

**PHENOPHASE (BBCH SCALE) BASED NITROGEN AND
ZINC SCHEDULING FOR YIELD AND ZINC
BIOFORTICATION IN DIRECT SEEDED RICE
(*Oryza sativa* L.)**



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Master of Science (Agriculture)

In

Agronomy

Supervisor

Dr. S. K. Prasad

Submitted by

Sandeep Kumar

**DEPARTMENT OF AGRONOMY
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Through: The Head, Department of Agronomy, Institute of Agricultural Sciences,
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Dear Sir,

I have great pleasure in forwarding the thesis entitled “**Phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice (*Oryza sativa* L.)**” submitted by **Mr. Sandeep Kumar, I.D. No. A-14013**, in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture) in Agronomy**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, (U.P.) and placing on record that he has completed the requisite residential requirements as contained in the statutes of the university.

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Supervisor

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2016

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*At the outset, being the student of this great Institute, I bow my head with great reverence to the lotus feet of **Bharat Ratan Mahamana Pandit Madan Mohan Malviya Ji**, the founder of the Banaras Hindu University, whose everlasting desire was to serve mankind. I am fortunate to perceive the prodigious path to tread upon precisely through precious guidance in this university.*

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Place:

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Per cent	Fig.	Figure
@	At the rate of	NS	Non-significant
°C	Degree centigrade	DAS	Days after sowing
m	Meter	N	Nitrogen
cm	Centimeter	P	Phosphorus
mm	Millimeter	K	Potassium
t	Tonnes	Z	Zinc
q	Quintal	B: C	Benefit cost ratio
kg	Kilogram	C.D.	Critical difference
mg	milligram	Max.	Maximum
g	Gram	Min.	Minimum
ha	Hectare	No.	Number
m ha	Million hectare	pH	Puissance he hydrogen
<i>i.e.</i>	Id est.(that is)	SEm $\pm$	Standard error of mean
<i>et al.</i>	And others	/	Per
<i>viz.</i>	Namely	hrs	Hours
e.g.	For example	₹	Rupees
d.f.	Degree of freedom	ha ⁻¹	Per hectare
dSm ⁻¹	Decisiemen per meter	L	Litre
EC	Electrical conductivity		

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INTRODUCTION

Rice (*Oryza sativa* L) is the primary food of about 65% of the world's population (FAO, 2014) and consumed by more than 75% in Asian countries (Ameen *et al.* 2014). In global scenario, it occupied 164.72 million hectare with annual production of 745.70 million tons (FAO, 2014) and widely cultivated cereals and playing critical roles in food and nutritional security especially in South Asia and East Asia. Asia accounts for 90% of the world's production and consumption of rice because of its favourable warm and humid climate (FAO, 2014). India has the world's largest area under rice with 44.0 million ha and is the second largest producer next only to China and contributes 21.5 percent of global rice production (Viraktamath *et al.* 2011). The average production of rice in India, at present, is 106.54 MT with average productivity of 2.4 tons/ha, which is far below the global average of 2.7 tons/ha. (DoAC, 2014). Out of the total 44 million ha of rice area in the country, 18.8 million ha is under rainfed condition, of which 67% lies in the eastern India (Mohapatra *et al.* 2013). In India, rice occupies one-quarter of the total cropped area, contributes about 40 to 43 percent of total food grain production and continues to play a vital role in the national food and livelihood security system (Viraktamath *et al.* 2011).

In Asia, rice is commonly grown by transplanting seedlings into puddled soil. Puddling benefits rice by reducing water percolation losses, controlling weeds, facilitating easy seedling establishment, and creating anaerobic conditions to enhance nutrient availability (Sanchez, 1973). But, repeated puddling adversely affects soil physical properties by destroying soil aggregates, reducing permeability in subsurface layers, and forming hard- pans at shallow depths (Sharma et al ., 2003), all of which can negatively affect the following non-rice upland crop in rotation (Hobbs and Gupta, 2000; Tripathi et al ., 2005). Moreover, puddling and transplanting require large amount of water and labour, both of which are becoming increasingly scarce and expensive, making rice production less profitable. Also, the drudgery involved in

transplanting—a job largely done by women—is of serious concern. All these factors demand a major shift from puddled-transplanted rice production to direct seeding of rice (DSR) in irrigated areas. According to Pandey and Velasco (2005), low wages and adequate availability of water favour transplanting, whereas high wages and low water availability favour DSR. Direct-seeding of rice has several advantages over transplanting. In addition to higher economic returns, the direct-seeding of rice is easy to plant, less labour-intensive, consumes less water (Bhushan *et al.*, 2007; Jehangir *et al.*, 2007) and is conducive to mechanisation (Khade *et al.*, 1993). DSR is a major opportunity to change production practices to attain optimal plant density and high water productivity in water scarce areas. Now, new varieties have been developed for rainfed upland rice ecosystem. It covers about 6.0 million hectares in India, which accounts 13.5% of the total area under rice crop (Joshi *et al.* 2013).

Nitrogen occupies a unique position as a plant nutrient because rather high amounts are required compared to the other essential nutrients. It stimulates root growth and crop development as well as uptake of the other nutrients. Gregorio *et al.* (2000) has reported that the N level is an important favourable factor determining grain mineral content. Nitrogen is an essential element in determining rice grain yield and N fertilizer is one of the major inputs to paddy fields which have favourable effect of promoting tillering and increasing spikelet number per panicle (Qiao *et al.*, 2011).

Nitrogen is one of the most yield limiting nutrients in production around the world. Generally, N in crop plants has positive association with grain yield (Fageria and Baligar, 2005). N uptake by rice was very slow during early growth stages. Hence, fertilizer N application at high doses during these stages could be prone to losses (Ali *et al.*, 2014). Use of adequate rate and source of N is an important aspect in improving N uptake and use efficiency. The N limitation in crop production is associated with its low recovery efficiency (<50%) of applied fertilizers. The low recovery of N is associated with its losses in soil-plant systems mainly by volatilization, leaching, denitrification, and soil erosion. Hence, improving N use efficiency is fundamental in crop production to increase yields of grain crops, reduce cost of crop production and also environmental pollution.

Zinc is a critical micronutrient required for structural and functional integrity of biological membranes and for detoxification of highly aggressive free radicals (Cakmak, 2000). Zn plays multiple roles in basic biochemical processes such as enzyme catalysis or activation, protein synthesis, carbohydrate and auxin metabolism, chlorophyll production, pollen formation, cytochrome and nucleotide synthesis, maintenance of membrane integrity, and energy dissipation (Alloway 2009).

Zinc (Zn) deficiency is a well-documented global health problem and reliance on cereal based food induce Zn deficiency related health problem, such as impairments in physical growth, immune system and brain function (Wei *et al.* 2012). The total area under Zn deficiency is about 10 M ha in India (Singh *et al.* 2008). After nitrogen, zinc is the second most yield-limiting nutrient in rice (Quijano-Gueta *et al.* 2002). The response of rice crop to nitrogen fertilizers have been well documented, however the effects of N interaction with zinc application rates on yield and quality of rice are lacking. Non-judicious use of nitrogen fertilizer could further aggravate Zn deficiency in alkaline soils and suppress paddy growth and yield (Rashid, 1996). Nitrogen fertilization is found to enhance zinc contents of flooded rice, where urea performed better than NH_4NO_3 in increasing Zn contents (Singh and Singh, 1981). They observed that higher Zn contents in plant tissues by nitrogen application were due to better growth, increased Zn solubility and increased root efficiency for Zn uptake.

However, the effects of N on Zn concentration in rice grains are not unambiguous, though N fertilization on increasing nutrient concentration in other crops had been proved to be effective (Zebbarhet *et al.* 2002; Wangstrand *et al.* 2006). Furthermore, Zn accumulation in different organs of the rice plant has not been studied in detail yet. So, the aim of the present study was to evaluate the effect of N on the accumulation of Zn in the grains and other parts of the rice plant and to determine the optimum N rate at which the optimal Zn density in rice could be attained as well as grain yield.

Phenological development stages of plants play an important role in agricultural plant research. Phenology of rice crop can be studied by dealing with

particular life-history stages separately, such as germination, tillering, panicle initiation and booting. Each of these events occurs in its own calendar slot, but there is clearly some interdependence between them. The rice growth cycles mainly consists of three stages: vegetative, reproductive and maturation. The phenological stages are used as steps for simulating vegetative dynamics (leaf area index and roots) and harvested organ filling (grain). The two phenological scales are overlapped to each other: for example, the onset of panicle initiation (PI) can occur before maximum tillering stage. Phenology can help's to know the current situation of rice and plan cultivation practices. The rice phenology is quantized using extended *Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie* (BBCH) scale.

The BBCH scale is a system for a uniform coding of a decimal system, with 10 principal growth stages and up to 10 secondary ones. The phenophase starts with seed germination/sprouting of perennials, progressing through leaf production and extension growth to flowering and senescence. The different phenological growth stages are described, utilising both the two- and three-digit BBCH coding system. The two-digit code is useful when an overall description of plant development.

Hence, keeping in the view the importance of nitrogen and zinc for yield and zinc content in rice grain, the present investigation **“Phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice”** was conducted at Agricultural Research Farm, BHU, Varanasi with following broad objectives:

Objectives

- (i) To find out the growth, yields attributes and yield of rice under phenophase based nitrogen management.
- (ii) To assess agronomic zinc biofortification of zinc in rice.
- (iii) To work out the economics of different treatments.



REVIEW OF LITERATURE

Based on different experimental information an attempt has been made in this chapter to review the literature embracing the relevant references related to different aspects of nitrogen and zinc fertilizer on direct seeded rice. This information is mostly from Indian situation in which the experiment was conducted. However, some foreign literatures have also been cited in order to get useful information regarding the present investigation under the appropriate heads.

2.1 Effect of nitrogen

2.1.1 Growth attributes

Paul *et al.* (2016) conduct an experiment with four variety and four level of nitrogen viz. control (no urea), prilled urea (50 kg N ha⁻¹), one pellet (0.9g) of USG/4 hills of two adjacent rows (30 kg N ha⁻¹) was applied at 10 days after transplanting (DAT) and two pellets of USG (0.9g each) one applied at 10 DAT and the another at 45 DAT/4 hills of two adjacent rows (60 kg N ha⁻¹). Results of the experiment showed that levels of nitrogen had significant effect on plant height, number of tillers hill⁻¹ and leaf area index (LAI) of HYV transplant rice.

Manzoor *et al.* (2015) conducted an experiment with six nitrogen levels i.e. 0, 110, 133, 156, 179, and 202 kg ha and found that Plant height, tillers count per plant, panicle length, grains per panicle, 1000 grain weight and yield increased with application of nitrogen from 0 to 133 N kg ha.

Ali *et al.* (2014) conducted an experiment with four nitrogen level (0, 40, 80, 120 and 160 kg/ha) and four zinc levels (0, 8, 10, 12 and 14 kg/ha) and recorded maximum tillers, plant height and leaf area/m⁻² with 120 kg N/ha.

Azarpour *et al.* (2014) conducted experiment with four rice cultivars and four nitrogen fertilizer levels (0, 30, 60, and 90 Kg N/ha). They recorded significantly increase leaf area index (LAI), total dry weight, leaf dry weight, crop growth rate, relative growth rate, net assimilation rate, leaf area duration, leaf area ratio, leaf weight rate, specific leaf area and grain yield with 90 kg N/ha.

Jisan *et al.* (2014) examined the four levels of N viz. 0, 46, 60 and 75 kg ha⁻¹ with four rice varieties and found that tallest plant (111.70 cm), highest number of total tillers hill⁻¹ (12.34) with 75 kg N/ha.

Puteh *et al.* (2014) examined the three nitrogen doses (80, 120 and 160 kg ha⁻¹) with rice cultivars and reported tallest plant (119.5cm), highest leaf area, chlorophyll content, and number of total tillers hill⁻¹ (15.33) with 160kg N/ha.

ThiPhong and Moe (2014) conducted a pot experiment with treatments T₀ (no nitrogen application), T₁ (40:40:20), T₂ (50:50:0), T₃ (50:30:20), and T₄ (50:20:30), the ratios under parentheses indicating the percentages of total nitrogen applied at the basal, active tillering, and panicle initiation stages. They reported that highest tiller m⁻² and panicle number were recorded with T₂.

Gill and Walia (2013) conducted experimented with 4 nitrogen levels, (control, 75%, 100% and 125%) to DSR with half dose of nitrogen after 2 weeks and rest half of nitrogen was applied 5 weeks after sowing. The results showed that 125% of recommended dose of nitrogen produced significantly taller plant, higher leaf area, tillers and CGR as compared to all other levels of nitrogen.

Tabar *et al.* (2013) carry out an experiment with nitrogen 50,100 and 150 kg/ha and phosphorus fertilizer at 4 level 0, 30, 60 and 90 kg/ha under split plot design. The maximum plant height, stem height and total tiller was recorded with 150 kg N/ha.

YosefTabar (2012) investigated the effect of nitrogen and phosphorus fertilizer on growth and yield in rice. Nitrogen fertilizer @ 50,100 and 150 kg/ha was applied in main plot and phosphorus levels 4 level 0, 30, 60 and 90 kg/ha

in sub plot. Maximum tiller number was observed for 150 kg/ha nitrogen and minimum of that was obtained for 50 kg/ha nitrogen fertilizer.

Lawal and Lawal (2012) conducted experiment with four N rates (0, 40, 80 and 120 kg/ha) and two fertilizer placement methods (deep and surface placement) and reported maximum plant height and crop growth rate with 120 kgN/ha.

Alagesan and Raja (2011) conducted an experiment with five levels of nitrogen (40, 80, 120, 160 and 200 kg N ha⁻¹) and four equal splits viz. seedling, active tillering, panicle initiation and flowering. They reported that maximum tillers/m² (529) found with 160 kg N ha⁻¹.

Heiossny and Maftoun (2008) investigated with five N levels (0, 50, 100, 200, and 400 mg N kg⁻¹ soil) with four N sources [urea, sulfur-coated urea, ammonium sulfate, and ammonium chloride] and three Zn rates (0, 5 and 10 mg Zn kg⁻¹ soil as zinc sulfate), results showed that the highest leaf area, plant height and top dry weight was obtained with application of N 200 mg kg⁻¹ (ammonium sulfate).

Singh and Tripathi (2007) examined optimum nitrogen dose of N, result showed that maximum plant height, LAI, and dry weight was obtained with 120 kg N ha⁻¹.

2.1.2 Yield attributes and yield

Dubey *et al.* (2016) conducted an experiment with three levels of nitrogen i. e. 60, 120 and 180 kg N/ha combined with three Sulphur rate S 20, 40 and 60 kg/ha along with two levels of Zn 5 and 10 kg/ha and reported that maximum grain and straw yield of 61.38 and 86.58 q/ha was recorded at 180 kg N/ha.

Ahmad *et al.* (2015) conducted a field experiment with four levels of N (0, 80, 120, and 160 kg ha⁻¹) and five levels seed rates (20, 40, 60, 80, and 100 kg ha⁻¹) reported that Maximum yield was achieved at the highest N rate with a seed rate of at least 40–60 kg ha⁻¹, suggesting that DSR has a higher fertilizer N requirement than the recommended rate for PTR.

Azarpour *et al.* (2014) conducted an experiment with cultivar and nitrogen levels (0, 30, 60 and 90 Kg N/ha). They reported maximum grain yield (4328 kg/ha) with 90 kg/ha nitrogen and minimum grain yield with 0 kg N/ha (2734 kg/ha).

Jisan *et al.* (2014) examined the four levels of N viz. 0, 46, 60 and 75 kg ha⁻¹ with four rice varieties and found that grains panicle⁻¹ (133.6), 1000-grain weight (24.55 g), grain yield (5.64 t ha⁻¹), straw (6.70 t ha⁻¹) yield and harvest index (45.63 %) were obtained when N applied @ 75 kg ha⁻¹ and the lowest from the 0 kg N ha⁻¹.

Puteh *et al.* (2014) examined three nitrogen doses (80, 120 and 160 kg ha⁻¹) and reported highest number of effective tillers hill⁻¹, filled grains panicle⁻¹ (1147) and lowest number of unfilled grains panicle⁻¹ and higher dry matter partitioning to economic yield with N₁₂₀ and resulted the highest grain yield (6.93 t/h) both per hill and per hectare.

Hatamifar *et al.* (2013) conducted an experiment with three nitrogen level (0, 60 and 90 kg/ha⁻¹) and reported maximum grain yield with 90 kg N/ha⁻¹.

Maiti and Bhattacharya (2013) an experiment was conducted with three levels of N (90, 120 & 150 kg ha⁻¹) and three levels of K₂O (0, 40 & 80 kg ha⁻¹). Highest grain yield was obtained with 120 kg N ha⁻¹.

Devi and Sumathi (2013) reported that maximum number of effective tillers, number of filled grains per panicle, test weight, and yield was obtained with 150 kg N/ha.

Kumar and Dawson (2013) showed that maximum grains per panicle, grain yield, test weight and net return was obtained when 120 kg N was applied.

Gill and Walia (2013) experimented with four nitrogen levels, (0%, 75%, 100% and 125% of recommended dose of nitrogen). They recorded highest number of grain panicle⁻¹, test weight and spikelet with application of 125% of recommended dose of nitrogen and 88.44, 25.81 and 5.41% higher grain yield over the control, 75%

of recommended dose of nitrogen and 100% of recommended dose of nitrogen, respectively.

Maiti and Bhattacharya (2012) conducted experiment with three nitrogen levels *i.e* 90,120 & 150 kg ha⁻¹ and three levels of P₂O₅, 40, 60 & 80 kg ha⁻¹. They reported highest grain yield with 150 kg nitrogen and 60 kg P₂O₅/h.

Youseftabar (2012) studied with levels of nitrogen fertilizer at 100, 200 and 300 kg/ha in main plot with spilt application *i.e* T₁= (1/2 basal-1/2 mid tillering), T₂= (1/3 basal-1/3 mid tillering-1/3 panicle initiation) and T₃= (1/4 basal-1/4 mid tillering-1/4 panicle initiation-1/4 flowering) as sub plot. He reported highest test weight, filled grain and grain yield with 300 kg N/h (1/4 basal-1/4 mid tillering-1/4 panicle initiation-1/4 flowering).

Alagesan and Raja (2011) experiment was conducted with five levels of nitrogen (40,80, 120, 160 and 200 kg N ha⁻¹) and with four split application. They reported that grain yield increase 16.9, 11.8 and 7.1 per cent with the application of 40, 80 and 120 kg N ha⁻¹ over control. Application of 200 kg N ha⁻¹ reduced the grain yield by 9.5 per cent over 160 kg N ha⁻¹.

Islam *et al.* (2009) an experiment was carried out to assess the effect of four nitrogen levels viz. T₁ (full doze of urea *i.e* 215 kg urea ha⁻¹ at 15 DAT), T₂ (full doze of urea at two equal splits *i.e* ½ at 15 DAT + ½ at 30 DAT), T₃ (full doze of urea at two equal splits, ½ at 15 DAT + ½ at 55 DAT) and T₄ (full doze of urea at three equal splits, 1/3 at 15 DAT + 1/3 at 30 DAT + 1/3 at 55 DAT). The highest grain yield hill⁻¹ (45.25 g) was recorded with N applied in 3 equal splits at 1/3 at 15 DAT+ 1/3 at 30 DAT + 1/3 at 55 DAT (T₄).

Fageria *et al.* (2008) conducted an experiment with N rates 0, 50, 100, 150, 300, and 400 mg N kg⁻¹ of soil. Grain yield increased significantly in a quadratic fashion, when N rate was increased in the range of 0 to 400 mg kg⁻¹.

Iqbal *et al.* (2008) reported that panicle length, grains panicle⁻¹, grain yield increased up to 60 kg ha⁻¹ and thereafter decreased.

Alim *et al.* (2008) conducted experiment with different sources and doses of nitrogen, and reported highest number of spikelet's panicle⁻¹, dry weight of panicle⁻¹, and individual grain weight and grain growth rate with 60 kg N ha⁻¹.

Hosseiny and Maftoun (2008) conducted experiment with five N levels (0, 50, 100, 200, and 400 mg N kg⁻¹ soil with four N sources [urea (U), sulfur-coated urea (SCU), ammonium sulfate (AS), and ammonium chloride (AC)] and three Zn rates (0, 5, and 10 mg Zn kg⁻¹ soil as zinc sulfate). They reported highest grain yield with SCU which was followed by AS, AC and U. The apparent N recovery (ANR) increased with increasing N up to 200 mg kg⁻¹ as U, AS, and AC and declined thereafter.

Mannan *et al.* (2008) experimented with different level of nitrogen 0, 25, 50, 75 and 100 kg N ha⁻¹ and concluded that maximum number of panicles, panicle length, percentage of fertile spikelet and straw yield increased with the increase of nitrogen levels but the highest grain yield was obtained at 50-75 kg N ha⁻¹.

Das *et al.* (2008) experimented with four levels of nitrogen (0, 60, 120 and 180 kg/ha) and three levels of potassium (0, 40 and 80 kg/ha) and reported maximum grain and straw yield with 80 kg N/ha.

Singh and Tripathi (2007) reported that maximum panicles length m⁻¹ and weight of panicle, grains panicle⁻¹, test weight as well as highest grain yield of 58.57 q ha⁻¹ was obtained with 160 kg N ha⁻¹.

Rahman *et al.* (2007) experiment was conducted with four nitrogen level 0, 60, 80 and 100 kg N ha⁻¹. The highest number of effective tillers hill⁻¹ (9.20), maximum grains panicle⁻¹ (100.80), highest grain yield (5.34 t ha⁻¹) and harvest index (44.50%) were obtained with 80 kg N ha⁻¹. The highest straw yield (6.98 t ha⁻¹) was obtained at the highest nitrogen level (100 kg N ha⁻¹).

Singh and Tripathi (2007) reported that the increase N uptake and protein content with increase nitrogen dose up to 120 kg N ha⁻¹.

Manivannan *et al.* (2006) carried out an experiment with two rice hybrids, KRH 2 and DRRH 1 and three levels of nitrogen (90, 120 and 150 kg ha⁻¹). Result showed that maximum grain yield of 4.97 t ha⁻¹ was found with 90 kg N/ha.

2.1.3 Economics

Dubey *et al.* (2016) reported that the highest B: C ratio was obtained when 120 kg N was applied.

Malik *et al.* (2014) concluded that the highest B: C ratio was obtained when 120 kg N ha⁻¹ was applied.

Maiti and Bhattacharya (2013) reported that the maximum net returns at Rs. 16250.32 and 12037.03 ha⁻¹ with the benefit-cost ratio of 34.23 and 25.45 obtained when 120 kg N/h was applied.

Manivannan *et al.* (2006) reported that maximum benefit-cost ratio of 2.1 was found when 180 kg nitrogen /ha was applied.

2.2 Effect of zinc

2.2.1 Growth attributes

Plant growth characters comprise of plant height, number of tillers, number of leaves, dry matter accumulation and leaf area index (LAI) which together contribute for the growth of plant and finally to the crop yield. For the growth and development of the all plant the zinc is the one of the most micronutrient as improper application zinc application lead to the improper growth of the plant. So zinc should be applied at proper dose and at appropriate growth stages.

Arif *et al.* (2016) reported that Zn application significantly increased the growth parameter, chlorophyll contents and yield components. The increases in rice biological yield by Zn application were relatively high, indicating the necessity of Zn application to plants.

Gour *et al.* (2015) conducted an experiment with seven treatments included control, recommended dose of fertilizer (RDF) NPK @ 120:60:60 kg/ha, RDF + S, Zn, B (40:05:1.5 kg/ha), customized fertilizer with composition of N:P:K:Zn:B;11:32:13:0.9:0.24% @ 312.5 kg/ha, 75% RDF + 25% N through sewage sludge, 75% RDF + 25% N through vermin compost, 75% RDF + 25% N through *Sesbania*. Results showed that application of 40 kg S, 5 kg Zn and 1.5 kg B/ha along with recommended dose of NPK increased plant height, tiller number, 1,000-grain weight and grain yield of rice.

Nawaz *et al.* (2015) conducted an experiment with five treatments including T1 (Control; no ZnSO₄ application), T2 (application of ZnSO₄ alone at 10-15 days after transplanting (DAT), T3 (application of ZnSO₄ + NPK at puddling stage), T4 (application of ZnSO₄ + nitrogenous fertilizer at 20-25 DAT) and T5 (application of ZnSO₄ + NPK at 20-25 DAT) and observed that maximum plant height (98.94 cm), and number of tillers was recorded with the treatment where ZnSO₄ was applied at puddling stage along with recommended dose of NPK while the minimum plant height and number of tillers of 86.48cm was noted in control plot.

Rana and Kashif (2014) experiment conducted with ten treatment of zinc (source of zinc, dose, method of application) and recommended dose of N,P,K. They reported the soil applied Zn-EDTA (10.0 kg ha⁻¹) produced highest plant height, tillers plant⁻¹ (145 tillers) and chlorophyll content.

Kumar and Qureshi (2012) conducted an experiment for compare the transformation, redistribution, availability and relative effectiveness of Zn from different fertilizer sources viz. Zn-DTPA (Zinc chelated with di-ethylene tri-amine penta-acetic acid), Zn-EDTA (Zinc chelated with ethylene di-amine tetra-acetic acid), Zn-CH (Zinc chelated with a mixture of DTPA & EDTA) and ZnSO₄.7H₂O (Zinc sulphate hepta hydrate) applied at various zinc levels (5, 10 and 20 mg kg⁻¹) to an Inceptisols in a greenhouse experiment. The results of the greenhouse study showed that the application of three zinc sources significantly increased wheat (*Triticum aestivum* L.) and succeeding maize (*Zea mays* L.) dry matter yield and shoot/root ratio compared with the control at increased levels of zinc.

Muamba and Ambara (2013) reported highest plant height 129 cm obtained when 30kg ZnSO₄/ha was applied.

Boonchuay *et al.* (2013) observed the foliar application of Zn at various growth stages and frequencies had no significant effect on growth attributes *viz*, plant dry weight, plant height, leaf area index and number of tillers.

Muthukumararaja and Sriramachandrasekharan (2012) conducted a pot experiment and reported that dry matter production significantly increased with graded dose of zinc over control. The maximum dry matter production of 2.98 g pot⁻¹ at tillering and 40.93 g pot⁻¹ at panicle initiation was obtained with application of 5 mg Zn kg⁻¹ which was about 44 to 60% greater as compared over control.

Keram *et al.* (2012) conducted an experiment and reported that maximum plant height, dry matter, chlorophyll content, leaf area index and number of tillers with recommended dose of NPK+20 kg Zn ha⁻¹.

Jat *et al.* (2011) reported that the highest agronomic efficiency (AE) was obtained with the application of 2% Zn-enriched urea (ZnSO₄.7H₂O). Physiological efficiency (PE) and Zn harvest index (Zn HI) of applied Zn were also significant influenced due to dual purpose summer legumes and applied in aromatic hybrid rice.

Mandal *et al.* (2009) showed that application of 10 kg Zn in three splits recorded significantly higher plant height, dry matter accumulation and tillers numbers.

Jana *et al.* (2009) conducted a field experiment to study the effect of zinc application on transplanted rice and reported that application of 30 to 40 kg ZnSO₄ ha⁻¹ produced significantly higher growth attributes of rice.

Shivay *et al.* (2008) showed that the Zn enriched-urea (3.5%) recorded significant maximum growth attributes such as plant height, leaf area index and dry matter of aromatic rice.

Naik and Das (2008) examined the relative performance of Zn-EDTA and ZnSO₄. Initial incorporation of Zn-EDTA showed pronounced effect on growth over ZnSO₄. The highest growth attributes such as plant height, dry matter and were recorded with application of 1 kg Zn ha⁻¹ as Zn-EDTA as basal.

Correia *et al.* (2008) studied on zinc forms and advocated that growth attributes were found maximum in Zn-EDTA than ZnSO₄ on rice.

Kumar *et al.* (2008) conducted experiments with four treatments (stubbles + ZnSO₄/Zn EDTA, Stubbles + FYM, Stubble + ZnSO₄/Zn EDTA + FYM and Stubbles). They reported application of stubbles + ZnSO₄/Zn EDTA + FYM recorded significantly higher plant height, plant dry matter and number of tillers over rest of the treatments.

Khan *et al.* (2007) evaluated the effect of different levels of zinc *i.e.* 0, 5, 10 and 15 kg ha⁻¹ along with the basal doses of 120 kg N, 90 kg P₂O₅ and 60 kg K₂O ha⁻¹. They reported maximum plant height of 74.38 cm and maximum number of (17.41) tillers plant⁻¹ with 10 kg Zn ha⁻¹, and lowest plant height of 59.50 cm was recorded in control.

2.2.2 Yield attributes and yield

For optimizing the yield of rice zinc should be applied as soil application or combination with the foliar application at appropriate growth stage for boosting the yield potential of the rice.

Yin *et al.* (2016) field experiment was conducted on a low Zn soil to determine the effect of different Zn fertilization strategies on grain Zn concentration and Zn allocation in different plant tissues of rice. Six treatments were used: (1) no Zn fertilization; (2) soil fertilization at transplanting; (3) Zn soil fertilization at transplanting and flowering; (4) foliar application during grain filling; (5) foliar applications during tillering, flowering, and grain filling; and (6) combination of treatments 3 and 5. Neither soil nor foliar application of Zn increased grain yield,

plant height, panicle length, or number of panicles per m². Compared to the control, foliar Zn application at three growth stages significantly increased shoot biomass.

Dubey *et al.* (2016) conducted an experiment with three levels of nitrogen i. e. 60, 120 and 180 kg N/ha and S 20, 40 and 60 kg/ha along with two levels of Zn 5 and 10 kg/ha and reported that Application of Zn substantially increased grain and straw yield and maximum grain and straw yield (56.55 and 79.16 q/ha) was recorded with 10 kg Zn/ha but significant increase was noted up to 5 kg Z/ha.

Haque *et al.* (2015) conducted an experiment to examine the long-term effects of S and Zn fertilization on rice yield and nutrient efficiency, levels of chemical fertilizers in NPKSZn treatment were applied with the rates of N-P-K-S-Zn as 80–25–35–20–5 kg ha⁻¹ and 120–25–35–20–5 kg ha⁻¹ in the wet and dry seasons, respectively and find that Zn fertilization was not effective in increasing grain yield in the wet season and increased only 3% in the dry season.

Khattak *et al.* (2015) experiment was conducted with four level of Zn (0, 5, 10 and 15 kg Zn ha⁻¹) as soil addition and three level of (0, 0.5 and 1 %) ZnSO₄ solution (0, 5 and 10 g ZnSO₄ per liter of de-ionized water) as foliar application and concluded that both soil addition and foliar spray of ZnSO₄ significantly increased grain yield and test weight, while its effect on biological yield was not significant.

Mahmudi *et al.* (2015) conducted an experiment with four levels of K doses (0, 50, 100 and 150 kg ha⁻¹) and Zn fertilization at three levels (0, 30 and 60 kg ha⁻¹). It was found that Zn fertilization had no significant effect on grain yield. However, the highest grain yield was observed in the treatment of 60 kg Zn ha⁻¹.

Rana and Kashif (2014) concluded maximum straw and grain yield was obtained when Zn-EDTA was applied @ 10.00 kg ha⁻¹ in soil.

Muamba and Ambara (2013) conducted experiment with three zinc doses (0, 20 & 30 kg/ha ZnSO₄) and they reported maximum effective tillers/m² and grain yield with 30 kg/ha of ZnSO₄.

Hussain *et al.* (2012) conducted an experiment with various Zn application methods to study Zn biofortification in wheat grain grown in a calcareous soil under glasshouse conditions. Wheat was treated with different Zn applications to soil (0, 4.5 or 9 mg Zn kg⁻¹), seed (100 mL of either 0 or 6.75 % Zn w/v sprayed on 1 kg seed) and foliage (distilled-water-sprayed control, 1 mL of 0.05 % Zn w/v at jointing, 2×1 mL of 0.50 % Zn w/v at heading or combined jointing and heading sprays) in all possible combinations.

Phattarakul *et al.* (2012) conducted an experiment to evaluate the effect of soil and/or foliar Zn fertilizer application on grain yield and found that Zn application increased grain yield by about 5 %.

Pooniya *et al.* (2012) conducted an experiment to evaluate the effects of summer green manuring crops and zinc fertilization on soil nutrient dynamics and productivity of basmati rice. They reported application of 2.0% ZEU as ZnSO₄. H₂O recorded the highest basmati rice grain yield (3.79 t ha⁻¹) and the increase was registered to the tune of 12.78%, 2.43%, 3.26%, 5.71%, 7.05% and 5.27% over control (only N), 2.0% ZEU as ZnO, 5 kg Zn ha⁻¹ as ZnSO₄.H₂O, 5 kg Zn ha⁻¹ as ZnO, 0.5 kg Zn as ZnO slurry and 1.0 kg Zn through 0.2% foliar spray, respectively.

Zou *et al.* (2012) reported combined application of soil and foliar Zn application increased grain yield whereas foliar Zn application did not cause any adverse effect on grain yield and even slightly improved the yield.

Pooniya and Shivay (2012) reported that application of 2.0% Zn-enriched urea (ZEU) as ZnSO₄. H₂O significantly influenced yield attributes and yield of basmati rice.

Muthukumararaja and Sriramachandrasekharan (2012) recorded maximum panicle m⁻², Grains panicle⁻¹, above ground biomass, grain , test weight and harvest index with application of Zn at 6 kg/ ha.

Keram *et al.* (2012) revealed that 10 kg Zn ha⁻¹ was statistically at par to 20 kg Zn ha⁻¹ in grain yield, straw yield and harvest index.

Rehman *et al.* (2012) reported that significant increases in grain yield, straw and grain Zn contents with foliar application of Zn as Zn-EDTA and ZnSO₄, but the highest increase was observed with Zn-EDTA application.

Shivay *et al.* (2012) experiment conducted on effect of zinc fertilization on yield attributes of rice, when 2% Zn-coating with zinc sulfate (ZnSO₄.7H₂O) was applied significantly increase partial factor productivity of applied Zn varied from 984-3387 kg grain kg Zn⁻¹, agronomic efficiency varied from 212-311 kg grain kg⁻¹ Zn (applied) and physiological efficiency of Zn varied from 6,384-17,077 kg grain kg⁻¹ Zn (absorbed). Thus, adequate Zn fertilization of basmati rice can lead to higher grain yield and Zn-denser grains.

Mustafa *et al.* (2011) conducted an experiment to evaluate the effect of different methods and timing of zinc application on growth and yield of rice. They reported method and timing of zinc application had significantly effect on paddy yield and maximum paddy yield was achieved in basal application at the rate of 25 kg ha⁻¹ and minimum paddy yield was noted in foliar application at 75 DAT with 0.5% Zn solution.

Saeed *et al.* (2011) conducted experiment with eight treatments viz. control, rice nursery root dipping in 0.5 % Zn solution, ZnSO₄ application at the rate of 25 kg ha⁻¹ as basal dose, foliar application of 0.5 % Zn solution at 15, 30, 45, 60 and 75 days after transplanting, and they reported maximum productive tillers per m⁻² (249.80) and yield (5.21 t ha⁻¹) with basal application at the rate 25 kg ha⁻¹ (21 %) ZnSO₄ and minimum yield and productive tillers per m⁻² (220.28) were recorded with foliar application at 60 DAT @ 0.5 % Zn solution.

Sridevi *et al.* (2010) reported positive effect of recommended dose of NPK +200 kg FYM enriched with 5.0 kg zinc, increased the grain and straw yields due to increased availability of zinc.

Naik and Das (2010) showed that split applications of 10 and 20 kg Zn ha⁻¹ as ZnSO₄ recorded 7.3 and 6% more grain yield respectively, over their corresponding basal application (10 and 20 kg Zn/ha at basal). However, basal application of Zn-

EDTA (1.0 kg Zn/ha through EDTA) resulted in a 2.8% increase in grain yield compared with its corresponding split applications (Zn 1.0 kg as Zn-EDTA in two splits).

Kumar and Kumar (2010) conducted an experiment to study the effect of rates and methods of zinc application in rice under flood prone conditions. There was a significant increase in yield and yield attributes of rice up to 45 kg ZnSO₄ ha⁻¹. Soil applied Zn proved superior as compared to its foliar application.

Mandal *et al.* (2009) advocated that, application of 10 kg Zn (5.0 + 2.5 + 2.5 kg ha⁻¹) in three splits in combination with recommended dose of NPK found significantly higher yield attributes, grain and straw yield..

2.2.3 Zinc content and uptake

In recent year the main emphasis is to increase the zinc content in grain of rice as well as in all the food grain. For effective translocation of the zinc to the edible part, zinc should be applied as soil as well as foliar at the later growth stage for boosting the zinc content in grain.

Yin *et al.* (2016) field experiment was conducted on a low Zn soil to determine the effect of different Zn fertilization strategies on grain Zn concentration and Zn allocation in different plant tissues of rice. Six treatments were used: (1) no Zn fertilization; (2) soil fertilization at transplanting; (3) Zn soil fertilization at transplanting and flowering; (4) foliar application during grain filling; (5) foliar applications during tillering, flowering, and grain filling; and (6) combination of treatments 3 and 5. Zn fertilization significantly increased Zn concentration in brown rice. The largest effect on grain Zn was observed by combination of soil and foliar applications. More increased Zn by Zn fertilization was allocated into straw not into grain.

Pooniya *et al.* (2014) conducted experiment with summer green manuring and Zn fertilization (2.0% Zn-enriched urea as zinc sulfate (ZnSO₄.H₂O) and 0.2% foliar spray of ZnSO₄.H₂O) and they found foliar spray of 0.2% (ZnSO₄.H₂O)

recorded the highest values of Zn concentration in grain and straw 24.1, 24.1 and 177.7, and 179.2 mg kg⁻¹ DM during 2008 and 2009, respectively. Whereas, 2.0% ZEU as ZnSO₄.H₂O recorded the highest total Zn uptake, 3081.6 and 3089.0 g ha⁻¹ in 2008 and 2009.

Guo *et al.* (2014) reported that foliar spray of Zn fertilizer evidently increased Zn content in rice than soil application. Effect of application method on Zn content followed a general trend as soil+ foliar > foliar spray > soil application > control.

Boonchuay *et al.* (2013) investigated the effect of different foliar zinc application at different growth stages and they reported application of Zn before flowering at panicle initiation or booting had no effect on Zn concentration in rice grain. But, Zn concentration was increased by 76% with one foliar Zn application at one week after flowering, by 164% at one week later, and by 264% when these two treatments were combined.

Phattarakul *et al.* (2012) conducted an experiment to evaluate the effect of soil and/or foliar Zn fertilizer application on grain Zn concentration and concluded that Zn concentration in brown rice was increased by 25 % and 32 % by foliar and foliar + soil Zn applications, respectively, and only 2.4 % by soil Zn application. Increase in grain Zn concentration by foliar Zn spray was significantly affected by the timing of the foliar application. More distinct increases in grain Zn by foliar Zn application were achieved when Zn was applied after flowering time, e.g., at early milk plus dough stages.

Shohag *et al.* (2012) reported that foliar Zn fertilization had significant impact on Zn concentration in brown rice and polished rice. Brown rice Zn concentration was significantly increased 30.28 mg kg⁻¹ in the control to 33.75 mg kg⁻¹ by foliar Zn-EDTA application, 35.07 mg kg⁻¹ by foliar Zn-Citrate application, 38.45 mg kg⁻¹ by foliar ZnSO₄ application, 39.84 mg kg⁻¹ by foliar Zn-AA application, these represented increases of 11.46%, 15.81%, 27.26% and 31.58%, respectively. Thus, foliar Zn fertilization could increase Zn concentration in brown rice and polished rice depending on Zn form.

Yadi *et al.* (2012) conducted an experiment with Zinc fertilization (0,20 and 40 kg/ha) and genotypes, and they reported highest zinc content in grain, zinc uptake in grain and straw, and nitrogen uptake in grain with 40 kg Zn ha.

Xue *et al.* (2012) reported that applying N at optimal rate (198 kg N ha⁻¹) resulted in significantly higher grain Zn concentration and especially grain content of Zn compared to no or lower N treatments. Further increasing N supply from optimal to excessive N supply resulted in non-significant increases in grain Zn concentration and content.

Zhang *et al.* (2012) reported that the concentration of Zn in grain was significantly affected by soil and foliar application of Zn and quoted the grain Zn concentration was positively correlated with foliar Zn rates.

Phattarakul *et al.* (2012) reported that Zn concentrations in brown and white rice were more effectively increased by Zn fertilization, especially with foliar Zn applications. On average, Zn concentration in brown rice was increased by 25 % and 32 % by foliar and foliar + soil Zn applications, respectively, and only 2.4 % by soil Zn application. In case of un-husked rice, foliar Zn application increased Zn concentration by about 66 %, but soil Zn application had only little effect. Further, the average increase in Zn concentration in white rice was 10 %, 15 % with soil and foliar Zn applications, respectively.

Wei *et al.* (2012) reported that regardless of cultivars, Zn concentration in brown rice was observed 30.28 mg kg⁻¹ in the control, 35.07 mg kg⁻¹ by foliar Zn-Citrate application, 38.45 mg kg⁻¹ by foliar ZnSO₄ application, 39.84 mg kg⁻¹ by foliar Zn-AA application, these represented increases of 15.81%, 27.26% and 31.58%, respectively. Furthermore, Zn concentration in polished rice was significantly increased by foliar Zn fertilization and recorded that 22.92 mg kg⁻¹ in the control, 26.09 mg kg⁻¹ by foliar Zn-Citrate application, 28.08 mg kg⁻¹ by foliar ZnSO₄ application, 28.67 mg kg⁻¹ by foliar Zn-AA application, these represented increases of 13.82%, 22.47% and 24.04%, respectively.

Muthukumararaja and Sriramachandrasekharan (2012) conducted a pot experiment and reported that the zinc concentration and uptake was significantly influenced by various levels of zinc applied to soil. The Zn concentration in grain ranged from 22.36 to 46.57 ppm and that of straw 19.74 to 43.95 ppm due to successive increment in zinc addition to soil. Zinc concentration and uptake showed highest with 7.5 mg Zn kg⁻¹ soil. The increase in the zinc content in grain and straw might be due to the presence of increased amount of Zn in soil solution by the application of zinc that facilitated greater absorption.

Narwal *et al.* (2011) reported that soil and foliar application of Zn, clearly enhanced grain Zn concentration over control, the most effective method for increasing Zn concentrations in straw and seed was foliar application that resulted in 1.0 to 5.5 and 1.0 to 2.1- fold increased respectively over control

Cao *et al.* (2010) a field experiment was conducted to investigate the effect of different Zn application methods on grain Zn concentration and Zn bioavailability. The result showed that the grain Zn concentration was increased by 6.1 %, 63.9 % and 82.6 % with soil application, foliar spray and soil + foliar application of Zn, respectively. The grain Zn uptake was increased by 3.6%, 69% and 83% respectively, however soil + foliar application of Zn proved superiority over soil and foliar application of zinc.

Jana *et al.* (2009) reported that zinc application produced significantly higher uptake of NPK and Zn in grain and straw of rice due to application of 30 to 40 kg ZnSO₄ ha⁻¹.

Varshney *et al.* (2008) reported that Zn application on rice-wheat sequence, the concentration of Zn was more in wheat grain as compared to straw while the reverse was found true for rice. However, total zinc removal by hybrid rice was more than twice as compared to wheat. Application of ZnSO₄ significantly increased the DTPA-extractable Zn in soil but decreased with subsequent crop removal.

Fang *et al.* (2008) reported that application of Zn fertilizers to the soil is effective in increasing grain Zn concentrations in cereals growing on most, but not all

soils and foliar applications of either ZnSO_4 or Zn-chelates (Zn-EDTA) can increase grain Zn concentrations in plants with adequate Zn mobility in the phloem.

Cakmak (2008) reported the soil + foliar application method of Zn was most effective method for increasing Zn concentration in grain and recorded 3.5-fold increment in the grain Zn concentration.

2.2.4 Effect of zinc on quality of rice

Zn is critical to the control of gene transcription and the coordination of other biological processes regulated by proteins containing DNA-binding Zn-finger motifs (Rhodes and Klug, 1993). Food Zn content is very important for human health as the artificial supplementation of foods with essential minerals is often difficult to achieve, particularly in developing countries. Therefore, it has been suggested that increased level of Zn in staple foods, e.g., rice may play an important role in reducing Zn deficiency (Ruel and Bouis 1998; Graham *et al.* 1999; Welch and graham 1999). Zn deficiency is a serious nutritional problem, affecting an estimated one third of the world's population (Singh & Prasad 2015) and contributing to 0.8 million deaths per year.

Dubey *et al.* (2016) observed that Quality of rice like protein starch and amylose content increased with the use of Sulphur and zinc.

Jat *et al.* (2011) observed that cooking quality parameters could be significantly improved by legume residue incorporation along with application of Zn-enriched urea. The N and Zn fertilization is directly responsible for higher 1,000-grain weight because N increased the crude protein content in grains (Naik and Das, 2008)

2.2.5 Economics

Pooniya and Shivay (2012) advocated that the economics of Basmati rice, summer green manuring crop residue incorporation (SGMI) and 2.0% ZEU ($\text{ZnSO}_4 \cdot \text{H}_2\text{O}$) Zn fertilization treatments gave the highest gross (SGMI, 85,985 and 91,582 INR ha^{-1} ; 2.0% ZEU, 89,837 and 59,851 INR ha^{-1}) and net returns (SGMI,

56,997 and 61,445 INR ha⁻¹; 2.0% ZEU, 59,851 and 64,442 INR ha⁻¹) during 2008 and 2009, respectively, compared with remaining of the treatments.

Jat *et al.* (2011) recorded highest net returns and B:C ratio of the legume-rice sequence with the legume residue incorporation and with the application of Zn-enriched urea in the aromatic hybrid rice.

Kumar and Kumar (2010) studied the effect of rates and methods of zinc application in rice under flood prone conditions and they reported that soil applied Zn proved superior as compared to its foliar application. Soil application of 45 kg ZnSO₄ ha⁻¹ was the best, which recorded the highest net monetary return and B: C ratio.

Mandal *et al.* (2009) reported that, application of 10 kg Zn (5.0 + 2.5 + 2.5 kg ha⁻¹) in three splits in combination with recommended dose of NPK recorded significantly higher yield attributes, grain and straw yield and showed additional net return of Rs. 1,969 ha⁻¹. However, the benefit: cost ratio was highest (1.72) for the treatment recommended dose of NPK in combination with Zn (2.5 + 2.5 kg ha⁻¹ in two equal splits).

Varshvey *et al.* (2008) reported that different rates and frequencies of Zn clearly indicated that application of 10 kg Zn ha⁻¹ to rice in the first year and 5 kg Zn ha⁻¹ to rice in the second year proved most economical combination to sustain the productivity of hybrid rice- wheat sequence in the tarai region of Uttarakhand.

2.3 Interaction effect of N and Zn

2.3.1 Interaction effect of N and Zn on yield attributes and yield

Ali *et al.* (2014) reported that nitrogen and zinc interaction significantly improved the grain yield, yield components and all kernel quality parameters, except kernel amylose contents. Combined application of 120 kg N/ha and 14 kg Zn/ha produced the maximum grain yields at both sites (6.12 and 5.78 t/ha). This combination also yielded the maximum kernel lengths and widths, water absorption ratio and kernel protein contents.

Masum *et al.* (2013) conducted experiment with Five N levels viz. 0 (control), 50, 70, 90 and 110 kg ha⁻¹ N were utilized where urea was used as nitrogen source which top-dressed at three equal installments at 7, 25 and 40 DAT and three levels of Zn i.e. 0 (control), 2.5, and 5 kg ha⁻¹. From the result it was observed that the highest (4.56 t ha⁻¹) grain yield was obtained from 90 kg ha⁻¹ N application, on the other hand from 2.5 kg ha⁻¹ Zn (4.29 t ha⁻¹) application.

Rahman *et al.* (2012) experiment carryout with nine treatments T₁ (100 kg N ha⁻¹ as urea, with no zinc). T₂ (100 kg N ha⁻¹ as urea, with 10 kg ZnSO₄ h⁻¹). T₃ (100 kg N ha⁻¹ as AS, with no zinc). T₄ (100 kg N ha⁻¹ as AS with 10 kg ZnSO₄ ha⁻¹). T₅ (100 kg N ha⁻¹ as CAN with no zinc). T₆ (100 kg N ha⁻¹ as CAN) with 10 kg ZnSO₄ ha⁻¹) T₇ (100 kg N ha⁻¹ as AN with no zinc). Result showed significantly higher yield as 25% in grain and 14% in straw with T₄. Similarly, Singh *et al.* (2012) also reported that increasing levels of zinc increased wheat yield.

Keram *et al.* (2012) recorded maximum plant height, dry matter, leaf area index and number of tillers m⁻² with NPK + 20 kg Zn ha⁻¹ however it was statistically at par with NPK + 10 kg Zn ha⁻¹.

Lin *et al.* (2007) concluded experiment with three N fertilization and they reported that increased protein content by 0.23, 0.63 and 1.17 percent compared with control.

2.3.2 Zinc content and uptake

Singh and Singh (2012) pot experiment was conducted with nitrogen at the rate of 0, 80 and 160 ppm through urea, ammonium sulphate and ammonium nitrate with Zn at 0 and 10 ppm as zinc sulphate, and reported highest zinc uptake with 80 ppm N as ammonium sulphate, 10 ppm zinc and application of 80 ppm N increased the Zn concentration in rice plants significantly at tillering and heading and at maturity in grain and straw. But with further increase in N to 160 ppm the Zn concentration either did not increase or tended to decrease in comparison to 80 ppm N probably due to dilution effect.

Chandel *et al.* (2010) experiment carryout with nitrogen dose (80 and 120 kg N ha⁻¹) and rice genotype, significantly increase total zinc content in grain 7.9% under 80 kg/h⁻¹ to 8.34% under 120 kg/ha⁻¹.

Hosseiny *et al.* (2008) concluded that maximum yield was obtained with 200 mg N kg⁻¹ (SCU) and 10 mg Zn kg⁻¹ soil as zinc sulfate was applied.

Lin *et al.* (2007) conducted experiment with four N levels, *i.e.* 0, 80, 160 and 320 kg N/ha and two rice cultivar. The Zn concentrations in brown rice of IR64 and IR68144 were increased by 16.0% and 20.21% compared with control respectively.



MATERIALS AND METHODS

The present experiment entitled, “**Phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice**” was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University during the *Kharif* (rainy) seasons of 2015. The details of materials used, experiment procedures followed and various techniques adopted during the experimentation have been presented in this chapter.

3.1 Experimental details

3.1.1 Experimental site

The experiment was carried out at the Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. It is located in the South Eastern part of Varanasi at 25°18' N Latitude, 83°03' E longitude and at an altitude of 75.7 meters above the mean sea level in the Northern Gangetic alluvial plains. The experiment was laid out in field number A/14 of Research Farm. The experimental site was homogeneously fertile with even topography and uniform textural make up as well as adjoining the main irrigation channel connecting the farm tube well for quick, regular and timely irrigation. Proper drainage facility was also provided in order to remove excess water during experimental period.

The area has been categorized under moisture deficit zone IV with a moisture deficit index (MDI) of -02 to -40. The length of growing season under *Kharif* condition (rainy seasons) is of about 180 days extending from standard meteorological week (SMW) from 30 (July 23 - 29) to 47 (November 19 - 25) enabling double cropping.

3.1.2 Soil of the experimental site

The soil of the experimental site was homogeneous in fertility, uniform textural make-up land located southern end of the city at the left bank of the river Ganga. It falls under North Gangetic plain, with typical Gangetic alluvium soils (order-inceptisols). To determine the physic-chemical properties of soil representative soil samples were collected from five different places before conducting the experiment from the depth of 0-20 cm, taking all possible precautions prescribed for soil sampling. One composite soil sample was made by thorough mixing of collected sample from different places. The soil sample brought to the laboratory and air dried and grinded to pass through a 100 mesh sieve before subjected to different physic-chemical properties following the standard method, the results thus obtained has been presented in table 3.1(a and b).

Table 3.1(a): Mechanical and physical properties of soil

S. No.	Particulars		Methods employed	References
1.	Mechanical analysis			
a.	Soil Separates (%)		Hydrometric method	Bouyoucos, 1962
	Sand	49.53		
	Silt	28.83		
	Clay	21.64		
b.	Texture	Sandy Clay Loam		
2.	Physical properties			
	Bulk density (g cm^{-3})	1.48	Core Sampler 100 (1-Db/Dp)	Piper, 1966
	Particle density (g cm^{-3})	2.60		
	Pore space (%)	44.51	Keen's box	Piper, 1966

Table 3.1(b): Chemical properties of soil

S. No.	Parameters	values	Methods employed	
1.	pH (1:2.5 soil: water suspension) 25°C	7.2	Buck man pH meter	Jackson, 1973
2.	Electrical conductivity (dSm ⁻¹ at 25°C) (1:2, soil: water suspension)	0.248	Systronics Electrical Conductivity Meter	Jackson, 1973
3.	Organic Carbon (%)	0.42	Walkley and Black Rapid Titration Method	Walkley and Black, 1934
4.	Available nitrogen (N)(kg ha ⁻¹)	199.0	Alkaline Potassium Permanganate Method	Subbiah and Asija, 1956
5.	Available P (kg ha ⁻¹)	24.64	Olsen's Method	Olsen <i>et al.</i> , 1954
6.	Available Potassium (kg ha ⁻¹)	210.5	Flame Photometric Method	Jackson, 1973
7.	Available Zinc (ppm)	0.50	DTPA Extraction	Lindsay and Norvell, 1978

It is quite evident from the data that the soil of the experimental plot was sandy clay loam in the texture, well drained and moderately fertile being low in available nitrogen, phosphorus and medium in available potassium. However it was deficient in Zn.

3.1.3 Climate and weather

3.1.3.1 Climatic condition

Varanasi has a sub- tropical climate, often subjected to extremes of weather condition *i.e.* very hot in the summer season and very cold in winter season. The

temperature begins to rise from the middle of February and reaches to its maximum by May or the middle of June. The coldest period of the year falls in between the last week of December and first week of January.

The maximum temperature fluctuates between 23°C to 40.6°C, while the variation in minimum temperature remains in between 5.0°C to 24.5°C. The normal period for the onset of monsoon in this zone has third week of June which lasts up to the end of September though sometimes it continue to the first week of October.

The area occasionally experiences cyclonic rains during winter seasons *i.e.* December to February. The period of March to May is generally dry. The average annual rain fall of this region amounts to 1081.6 mm, of which 845.5 mm is received during rainy season. The percentage distribution of annual rainfall *i.e.* 87.33 percent during rainy season from June to September (monsoon season), 12.67 per cent during post rainy season (9.8 per cent from October to February and 2.8 percent from March to May).

The mean annual potential evapotranspiration (PET) is 1525 mm. The mean relative humidity is 88 per cent which rises up to 91 % during July to September and falls down to 39 per cent during the end of April to early June.

3.1.3.2 Weather condition during crop season

The meteorological data during the experimental period was obtained from the meteorological observatory of All India Coordinated Research Project for Dry land Agriculture situated at Agricultural Research Farm of Banaras Hindu University; Varanasi has been presented in Table 3.2 and graphically shown in Fig. 3.1.

The total rainfall received during experimentation was 396.7 mm in 2015. The maximum rainfall was received at August during the year of experimentation.

Table 3.2 Meteorological data during crop season (2015)

Standard week no.	Month & Date	Rainfall (mm)	Temperature (°C)		R.H. (%)		Wind Speed (km/hr)	Sunshine (hours)	Evaporation (mm)
			Max.	Min.	Max.	Min.			
30	July,23-29	54.0	33.2	26.4	85	64	5.0	6.2	5.1
31	30-05	81.2	31.6	25.4	86	69	5.0	4.8	1.4
32	Aug, 06-12	18.6	34.0	26.7	85	67	1.9	5.2	4.2
33	13-19	116.3	32.7	27.1	89	77	4.2	6.0	4.4
34	20-26	49.5	33.2	25.7	87	72	6.4	5.9	4.9
35	27-02	42.2	33.4	26.7	90	74	3.0	4.5	3.6
36	Sep, 03-09	0.0	34.6	26.3	80	59	4.0	8.8	4.2
37	10-16	0.0	24.6	27.5	86	64	3.1	7.3	3.7
38	17-23	11.9	31.1	26.9	87	66	5.0	6.9	4.3
39	24-30	0.0	33.3	23.8	80	54	3.4	8.8	3.2
40	Oct, 01-07	0.0	34.0	22.8	83	51	1.3	9.0	3.0
41	08-14	0.0	33.5	22.0	82	52	1.8	8.6	3.2
42	15-21	0.0	33.0	21.8	79	59	1.5	8.0	3.1
43	22-28	0.0	32.1	19.0	88	56	0.3	8.3	2.7
44	29-04	23.0	28.0	16.6	93	82	1.4	5.2	2.0
45	Nov, 05-11	0.0	30.6	18.6	89	49	0.8	5.7	2.6
46	12-18	0.0	30.4	16.6	89	40	1.8	7.6	2.5
47	19-25	0.0	28.7	16.2	90	49	0.7	4.4	1.4

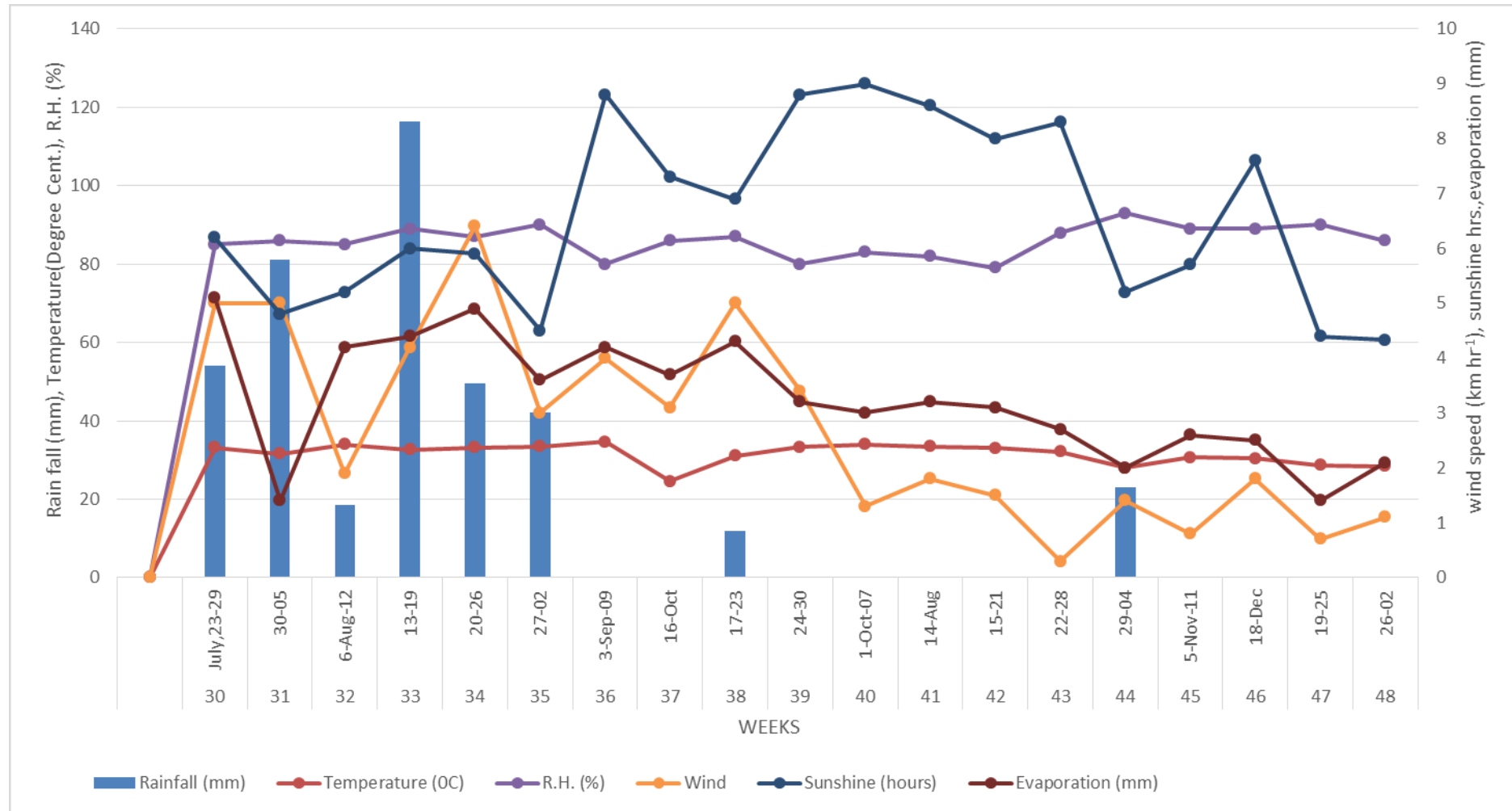


Fig. 3.1. Weather condition during crop season.

The maximum and minimum temperature varied between 24.60-34.60⁰C and 16.20-27.50⁰C. The maximum and minimum humidity varied between 79-93 per cent and 40-82 per cent in the year. During the year of experimentation sunshine hours varied between 4.4-9.0 hours. The evaporation data was recorded from USWB Class a Pan Evaporimeter revealed the average weekly evaporation varied from 1.4 to 5.1 mm.

3.2 Cropping history of the experimental field

Cropping pattern followed on a particular field will affect the production potential of the field. The details of cropping history of the experimental field, preceding the period of experimentation is given in Table 3.3. wheat crop was taken before the experimental crop.

Table 3.3: Cropping history of the experimental field

Year	Season		Remark
	<i>Kharif</i>	<i>Rabi</i>	
2012-2014	Rice	Wheat	-
2014-2015	Rice	Wheat	-
2015	Rice*	-	Experimental Year

*Experimental crop

3.3 Experimental details

3.3.1 Layout of the experiment

To fulfill the objective of the investigation the field experiment was laid out in randomized block design (factorial) with 15 treatment combinations, consisting of three nitrogen level and five zinc treatments. The whole experimental area was divided into three equal blocks, each representing a replication. Each replication was further divided into two blocks. Each block was further divided into eight equal plots

and each replication the treatment combination was allocated randomly. The detail of layout are given below and illustrated through Fig. 3.2.

Table 3.4: Details of layout of Experimental Field

S. No. Particulars		
1.	Design	Randomized block design (Factorial)
2.	Total number of treatment combinations	5x3=15
3.	Replication	3
4.	Total number of plots	15 x 3 =45
5.	Gross plot size	4.25 x 3.6 m ²
6.	Net plot size	3.45 x 3.2 m ²
7.	Row to row spacing	20 cm
8.	Field border	1.0 m
9.	Block border	1.0 m
10.	Plot border	0.5 m
11.	Width of ridges	0.5 m
12.	Total area of experimental fields	1063.3 m ²
13.	Irrigation channel	
a.	Main irrigation channels	1.0 m
b.	Sub irrigation channels	1.0 m

Field Border (1m)													
Main irrigation channel (1m)													
← R ₁ →				← R ₂ →				← R ₃ →					
Field Border(1m)	Irrigation channel (1m)	N ₂ Z ₃	Replication Border(0.5 m)	N ₁ Z ₁	Irrigation channel (1m)	N ₀ Z ₄	Replication Border(0.5 cm)	N ₀ Z ₁	Irrigation channel (1m)	N ₀ Z ₂	Replication Border(0.5 m)	N ₂ Z ₁	Field Border(1m)
		N ₀ Z ₄		N ₂ Z ₀		N ₁ Z ₄		N ₂ Z ₃		N ₂ Z ₂		N ₁ Z ₀	
		N ₀ Z ₀		N ₀ Z ₃		N ₂ Z ₄		N ₀ Z ₃		N ₁ Z ₄		N ₀ Z ₀	
		N ₁ Z ₃		N ₁ Z ₀		N ₂ Z ₀		N ₁ Z ₃		N ₀ Z ₁		N ₁ Z ₂	
		N ₂ Z ₁		N ₁ Z ₂		N ₁ Z ₀		N ₂ Z ₂		N ₀ Z ₄		N ₁ Z ₁	
		N ₀ Z ₂		N ₁ Z ₄		N ₁ Z ₁		N ₂ Z ₁		N ₂ Z ₀		N ₀ Z ₃	
		N ₂ Z ₂		N ₂ Z ₃		N ₀ Z ₀		N ₀ Z ₂		N ₂ Z ₃		N ₁ Z ₃	
		N ₀ Z ₁		-		N ₁ Z ₂		-		N ₂ Z ₄		-	
		Field Border (1m)											

Fig. 3.2. Layout plan

Table 3.5: Treatment details

Nitrogen levels		
N ₀	-	0 kg N/ha. (Control)
N ₁	-	120 kg N/ha (50% at sowing +25% at G 21 + 25% at G 32)
N ₂	-	160 kg N/ha (50% at sowing +25% at G 21 + 25% at G 32)
Time of Zinc Application		
Z ₀	-	0 kg Zn / ha. (Control)
Z ₁	-	5 kg Zn /ha at basal + 0.3 % ZnSO ₄ .H ₂ O spray at G 45 + 0.3 % ZnSO ₄ .H ₂ O spray at G 61
Z ₂	-	10 kg Zn /ha at basal + 0.3% ZnSO ₄ .H ₂ O spray at G 45 + 0.3% ZnSO ₄ .H ₂ O spray at G 61
Z ₃	-	5 kg Zn /ha at basal +0.3 % ZnSO ₄ .H ₂ O spray at G 51 + 0.3 % ZnSO ₄ .H ₂ O spray at G 73
Z ₄	-	10 kg Zn /ha at basal +0.3 % ZnSO ₄ .H ₂ O spray at G 51 + 0.3 % ZnSO ₄ .H ₂ O spray at G 73
G 21 = 1 tiller detected		
G 32 = Panicle formation; panicle 1-2 mm long		
G 45 = Late booting		
G 51 = Tip of inflorescence emerged		
G 61 = Anthesis; anther visible at top of panicle		
G 73 = Early milk		

3.3.2 Treatment combination

Total numbers of treatment combinations were fifteen comprising of nitrogen level and zinc combinations are presented in Table 3.6.

Table 3.6: Treatment combination

Treatments	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄
N ₀	N ₀ Z ₀	N ₀ Z ₁	N ₀ Z ₂	N ₀ Z ₃	N ₀ Z ₄
N ₁	N ₁ Z ₀	N ₁ Z ₁	N ₁ Z ₂	N ₁ Z ₃	N ₁ Z ₄
N ₂	N ₂ Z ₀	N ₂ Z ₁	N ₂ Z ₂	N ₂ Z ₃	N ₂ Z ₄

3.4 Cultural operation

Details of various cultural operations carried out during the experimentation have been presented in table 3.7.

3.5 Field preparation

The experimental site was ploughed with tractor drawn MB plough followed by two harrowing after the harvest of winter crop. Thereafter, the field was puddled with the cultivator and planked. Thereafter lay out was done according to prepared plan of layout (design) presented in Table 3.4.

Table 3.7: Details of field operations carried out experiment.

S. No.	Operations	2015
1.	Land preparation	
a.	Deep ploughing	23-07-2015
b.	Puddling	25-07-2015
c.	Layout	26-07-2015
2.	Sowing and fertilizer application	27-07-2015
3.	Gap filling	22-08-2015
4.	Fertilizer application	
a.	Basal applications of N, P, and K.	27-07-2015
b.	Top dressing of N at G 21	Appendices IV
c.	Top dressing of N at G 32	Appendices IV
5.	Foliar application	
a.	Foliar application of ZnSo ₄ .H ₂ O at G 45	Appendices IV
b.	Foliar application of ZnSo ₄ .H ₂ O at G 51	Appendices IV
c.	Foliar application of ZnSo ₄ .H ₂ O at G 61	Appendices IV
d.	Foliar application of ZnSo ₄ .H ₂ O at G 73	Appendices IV
6.	Weeding	
a.	1st Hand weeding	20.08.2015
b.	2nd Hand weeding	08-09-2015
7.	Irrigation	
	First irrigation	01-08-2015
	2nd irrigation	11-09-2015
	3rd irrigation	02-10-2015
8.	Harvesting	24-11-2015
9.	Threshing	10-12-2015

3.6 Seed and sowing

As per layout design of experimental field lines were drawn 20 cm apart on the field with the help of a rope and rice seeds were broadcast directly under puddled condition, seed rate was taken @ 50 kg/ha (77 gram/plot) .

3.7 Fertilizer application

At the time of sowing half of recommended rate of nitrogen and full rate of P and K was applied and remaining nitrogen was applied in two equal split rate at G 21 and G 32 of BBCH scale. Urea, SSP & MOP used as a source of fertilizer.

ZnSO₄.H₂O (monohydrate) was use as a source of zinc fertilizer; foliar application was done at different BBCH phenophase such as G 45, G 51, G 61, and G 73. Apply as foliar application at different growth stage. For foliar application 0.3 % ZnSO₄.H₂O solution was prepared, for this solution preparation 74.50 g ZnSO₄.H₂O (24.59 g Zn) was taken to make the spray solution 24.8 liter (@ 500 lit/ha).

3.8 Gap-filling

At the time of sowing nursery was raised in the empty plots for the purpose of gap-filling in case of poor germination, after 25 DAS seedling was placed where germination was scattered.

3.9 Irrigation

First irrigation was done 4 DAS for proper germination of seed and subsequently irrigation was done based on requirement of the crop.

3.10 Weed management

For controlling the weeds, two manual weeding were done, first at 25 days and second at 40 days after sowing.

3.11 Harvesting

Experimental crop was harvested after it attained physiological maturity of grain. Matured crop were cut from the base with the help of sickle. First of all the

border rows were harvested and separated. Later, crop from each net plots were harvested and sun dried. The harvested material from each net plot was carefully bundled, weighed and brought to the threshing floor separately.

3.12 Threshing

The individual bundles from each plot were weighed and cleaned after complete sun drying. Threshing was done manually and the grain yield was recorded after winnowing and cleaning. The difference between the bundle weight and grain weight recorded as straw weight. Grain yield thus obtained from each plot were recorded as kg ha⁻¹.

3.13 The BBCH-scale

The BBCH-scale is a system for a uniform coding of phenologically similar growth stages of all mono- and dicotyledonous plant species. It results from teamwork between the German Federal Biological Research Centre for Agriculture and Forestry (BBA), the German Federal Office of Plant Varieties (BSA), the German Agrochemical Association (IVA) and the Institute for Vegetables and Ornamentals in Grossbeeren/Erfurt, Germany (IGZ). The decimal code, which is divided into principal and secondary growth stages, is based on the well-known cereal code developed by Zadoks *et al.* (1974) in order to avoid major changes from this widely used phonological key. The abbreviation **BBCH** derives from **B**iologische **B**undesanstalt, **B**undessortenamt and **C**hemical industry.

3.13.1 The basic principles of the scale

- The general scale forms the framework within which the individual scales are developed. It can also be used for those plant species for which no special scale is currently available.
- Similar phenological stages of each plant species are given the same code.
- For each code, a description is given, and for some important stages, drawings are included.
- For the description of the phenological development stages, clear and easily recognised (external) morphological characteristics are used.

- Except where stated otherwise, only the development of the main stem is taken into consideration.
- The growth stages refer to representative individual plants within the crop stand. Crop stand characteristics may also be considered.
- Relative values relating to species- and/or variety-specific ultimate sizes are used for the indication of sizes.
- The secondary growth stages 0 to 8 correspond to the respective ordinal numbers or percentage values. For example stage 3 could represent: 3rd true leaf, 3rd tiller, 3rd node or 30% of the final length or size typical of the species or 30% of the flowers open.
- Post-harvest or storage treatment is coded **99**.
- Seed treatment before planting is coded **00**.

3.13.2 Organization of the scale

The entire developmental cycle of the plants is subdivided into ten clearly recognizable and distinguishable longer-lasting developmental phases. These principal growth stages are described using numbers from 0 to 9 in ascending order. The principal growth stages are described in Table 3.8.

Table 3.8: Principal growth stages.

Principal growth stages		
S. No.	Stage description	G scale
1.	Germination / sprouting / bud development	0
2.	Leaf development (main shoot)	1
3.	Formation of side shoots / tillering	2
4.	Stem elongation or rosette growth / shoot development (main shoot)	3
5.	Development of harvestable vegetative plant parts or vegetatively propagated organs / booting (main shoot)	4
6.	Inflorescence emergence (main shoot) / heading	5
7.	Flowering (main shoot)	6
8.	Development of fruit	7
9.	Ripening or maturity of fruit and seed	8
10.	Senescence, beginning of dormancy	9

The principal growth stages alone are not sufficient to define exactly application or evaluation dates, since they always describe time spans in the course of the development of a plant. Secondary stages are used if points of time or steps in the plant development must be indicated precisely. In contrast to the principal growth stages they are defined as short developmental steps characteristic of the respective plant species, which are passed successively during the respective principal growth stage. They are also coded by using the figures 0 to 9. The combination of figures for the principal and the secondary stages, results in the two-digit code. The two-digit code is a scale which offers the possibility of precisely defining all phenological growth stages for the majority of plant species.

In case of the BBCH-scales the descriptions are based on the actual characteristic features of the individual plant. If the scales are used for the definition of the development stage of a plant stand, the description should apply to at least 50% of the plants. Greater differences in the course of the development of different plant groups have to be taken into consideration for the description of the general scale. This problem is dealt with by offering several definitions for one specific stage wherever the formulation of a uniform text is impossible.

The following letters show to which plant group the respective definition refers.

Table 3.9: Principal growth stage 0 (Germination)

G scale	Description
01	Dry seed (caryopsis)
02	Beginning of seed imbibition
03	Seed imbibition complete (pigeon breast)
05	Radicle emerged from caryopsis
06	Radicle elongated, root hairs and/or side roots visible
07	Coleoptile emerged from caryopsis (in water-rice this stage occurs before stage 05)
09	Imperfect leaf emerges (still rolled) at the tip of the coleoptile

Table 3.10: Principal growth stage 1 (Leaf development)

G scale	Description
10	Imperfect leaf unrolled, tip of first true leaf visible
11	First leaf unfolded
12	2 leaves unfolded
13	3 leaves unfolded
15	5 leaves unfolded
19	9 or more leaves unfolded

Table 3.11: Principal growth stage 2 (Tillering)

G scale	Description
21	Beginning of tillering: first tiller detectable
22	2 tillers detectable
23	3 tillers detectable
29	Maximum number of tillers detectable

Table 3.12: Principal growth stage 3 (Stem elongation)

G scale	Description
30	Panicle initiation or green ring stage: chlorophyll accumulates in the stem tissue, forming a green ring
32	Panicle formation: panicle 1–2 mm in length
34	Internode elongation or jointing stage: internodes begin to elongate, panicle more than 2 mm long (variety-dependent)
37	Flag leaf just visible, still rolled, panicle moving upwards
39	Flag leaf stage: flag leaf unfolded, collar regions (auricle and ligule) of flag leaf and penultimate leaf aligned (pre-boot stage)

Table 3.13: Principal growth stage 4 (Booting)

G scale	Description
41	Early boot stage: upper part of stem slightly thickened, sheath of flag leaf about 5 cm out of penultimate leaf sheath
43	Mid boot stage: sheath of flag leaf 5–10 cm out of the penultimate leaf sheath
45	Late boot stage: flag leaf sheath swollen, sheath of flag leaf more than 10 cm out of penultimate leaf sheath
47	Flag leaf sheath opening
49	Flag leaf sheath open

Table 3.14: Principal growth stage 5 (Inflorescence emergence, heading)

G scale	Description
51	Beginning of panicle emergence: tip of inflorescence emerged from sheath
53	30% of panicle emerged
55	Middle of panicle emergence: neck node still in sheath
56	60% of panicle emerged
58	80% of panicle emerged
59	End of panicle emergence: neck node level with the flag leaf auricle, anthers not yet visible

Table 3.15: Principal growth stage 6 (Flowering, anthesis)

G scale	Description
61	Beginning of flowering: anthers visible at top of panicle
65	Full flowering: anthers visible on most spikelets
69	End of flowering: all spikelets have completed flowering but some dehydrated anthers may remain

Table 3.16: Principal growth stage 7 (Development of fruit)

G scale	Description
71	Watery ripe: first grains have reached half their final size
73	Early milk
75	Medium milk: grain content milky
77	Late milk

Table 3.17: Principal growth stage 8 (Ripening)

G scale	Description
83	Early dough
85	Soft dough: grain content soft but dry, fingernail impression not held, grains and glumes still green
87	Hard dough: grain content solid, fingernail impression held
89	Fully ripe: grain hard, difficult to divide with thumbnail

Table 3.18: Principal growth stage 9 (Senescence)

G scale	Description
92	Over-ripe: grain very hard, cannot be dented by thumbnail
97	Plant dead and collapsing
99	Harvested product

3.14 Biometrical observations

During the investigation biometric observations were recorded with all the precautions so as to reduce sampling errors. For recording biometric observations at a regular interval of 30 days *i.e.* 30th, 60th, 90th days after sowing (DAS) and at harvest, three plants from the net plot area were randomly selected and tagged. However, for the dry matter accumulation, five plants were randomly selected from the sample rows (border plot area) at regular interval. While; for observations of yield attributing parameters, three tagged plants were harvested. The plants were then tagged and brought to the laboratory for the study.

3.14. 1 Growth attributes

Observation on growth character *viz.*, plant height (cm), number of tillers plant⁻¹, chlorophyll content (SPAD value), crop growth rate (CGR), relative growth rate (RGR), leaf area index (LAI), dry weight (g running m⁻¹) of shoot & root at 30, 60, 90 DAS and harvest were recorded during the crop season.

3.14.1.1 Plant height (cm)

Height of the plant is one of major growth attribute and is measured from base of soil to the topped flag leaf. Accordingly the height of three tagged plants were measured in cm. from ground level to the tallest leaf of the plant at different stages of crop growth and average mean of height was recorded.

3.14.1.2 Number of tillers (per running m)

The production of tillers from marked row were counted at 30, 60, 90 DAS and at harvest stage. At final stage *i.e.* harvest, tillers were separated into effective (Productive) and ineffective (unproductive) tillers per running meter and their average

was recorded both for effective as well as ineffective tillers per running m⁻¹. The productions of effective tillers are the important components to decide yield of rice. The number of productive tillers per running m⁻¹ were counted at harvesting at three different places of each plot and expressed as effective tillers running m⁻¹.

3.14.1.3 Shoot dry matter accumulation (g running m⁻¹)

For recording dry matter production per running meter selected from the sampling rows from ground level with the help of sharp knife at different crop growth stages *i.e.* 30, 60, 90 DAT and at harvest. The destructive samples of such plants were oven dried at 60 ± 1⁰ C for 48 hours and weighed. The weight thus obtained is expressed as dry weight running m⁻¹ (g).

3.14.1.4 Leaf area index

Running meter was selected and respective tiller number running m⁻¹ was counted. Length and maximum width of each leaf were measured and the area of each leaf was computed on the basis of the following formula (Gomez, 1972).

$$\text{Leaf area} = K \times L \times W$$

Where, K is adjustment factor. The value of K was 0.75 for the stage up to 60 DAT and 0.67 at harvest. Subsequently leaf area running m⁻¹ and leaf area index (LAI) were computed with the following formula.

$$\text{Leaf area running m}^{-1} = \text{Leaf area} \times \text{total leaves (No.) running m}^{-1}$$

$$\text{LAI} = \frac{\text{Leaf area running m}^{-1} (\text{cm}^2)}{\text{Land area (cm}^2\text{)}}$$

3.14.1.5 Chlorophyll content (SPAD value)

The SPAD-502, a hand held chlorophyll meter (Minolta corporation, Ramsey, N.J.) was used for rapid non-destructive estimation of extractable chlorophyll in green leaves (Earl and Tollenaar, 1997). This instrument uses a silicon photo-iodide

to detect transmittance of light emitted by two light emitting diodes- through a leaf sample, one with peak emittance at 650 nm, where absorbance by chlorophyll is high and relatively unaffected by carotene and another with peak emittance at 940 nm, where absorbance by chlorophyll is negligible. The SPAD reading that is correlated with leaf chlorophyll concentration is calculated from the transmittance through leaf tissue at these two wavelengths. Chlorophyll content of randomly selected 20 sampled leaves from various rice plant in net plot area was measured at 30, 60, 90 DAS coinciding with tillering, booting and panicle emergence stage of the crop. Finally, the average value on chlorophyll content were computed and expressed in SPAD unit.

3.15 Yield attributes and yield

3.15.1 Effective tillers (per running m⁻¹)

Effective tillers number running m⁻¹ were counted with the help of scale and expressed as effective tillers per running m⁻¹.

3.15.2 Panicle weight (g)

Ten randomly selected panicles were weighed and after taking average recorded as panicle weight.

3.15.3 Panicle length (cm)

Ten panicles were randomly selected from tagged plants and the length was measured from the neck nodes to the tip of the upper most spikelet and average length was recorded as panicle length.

3.15.4 Number of grains per panicle

Total number of grains were worked out by taking 5 randomly selected panicles from each plot and expressed as average number of grain panicle⁻¹.

3.15.5 Test weight (g)

Out of the total grain yield produced from each plot thousand filled grains were counted and weighed on electronic balance to record test weight of thousand grains.

3.15.6 Grain yield (kg ha⁻¹)

The mature harvested produce from the net plot area was sun dried and threshed to obtain grain yield in kg per plot. The moisture percentage in 100 g samples drawn from each treatment were recorded with the help of moisture meter and there after the yield thus obtained was adjusted to 14% moisture and finally the yield of net plot was recorded in kg ha⁻¹.

3.15.7 Straw yield (kg ha⁻¹)

The straw yield was worked out by deducting the grain yield from total biological yield and recorded as kg ha⁻¹.

3.15.8 Biological yield (kg ha⁻¹)

It was calculated from all the above ground plants part of each net plot will sun dried and weight in kg/plot. And these values were expressed into kg ha⁻¹.

3.15.9 Harvest index (%)

The harvest index (H.I.) was calculated by dividing economical yield (% grain yield) by the biological yield (grain and straw) and represented in percentage (Donald and Hamblin, 1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

$$\text{Biological Yield} = \text{Grain yield} + \text{Straw yield}.$$

3.16 Quality parameters

3.16.1 Protein content (%)

Protein content (%) in grain was worked out by multiplying the nitrogen content in grain by the factor 6.25 (A.O.A.C., 1970).

3.16.2 Protein harvest

The protein harvest (kg ha^{-1}) was obtained by the following formula.

$$\text{Protein harvest (kg ha}^{-1}\text{)} = \frac{\text{Protein content} \times \text{Yield}}{\text{Weight of rough rice}} \times 100$$

3.17 Soil analysis

3.17.1 Physical properties

3.17.1.1 Bulk density

Bulk density of the soil samples was determined using pycnometer as describe by Piper (1966).

3.17.1.2 Porosity

Porosity of the soil samples was determined using pycnometer as described by Piper (1966).

3.17.2 Chemical properties

3.17.2.1 pH

A soil water suspension was prepared in the ratio of 1:2.5 (20 g of soil and 50 ml distilled water) and pH was recorded with the help of glass electrode digital pH meter as described by Jackson (1973).

3.17.2.2 Electrical conductivity (EC)

A soil water suspension was prepared in the ratio of 1:2.5 (20 g of soil and 50 ml of distilled water) and EC was measured with the help of Conductivity Bridge at room temperature as described by Jackson (1973). The scale reading (mhos cm^{-1}) was converted to dSm^{-1} using the following formula:

$$\text{EC (dS m}^{-1}\text{)} = \text{Scale reading} \times \text{cell constant}/1000$$

3.17.2.3 Organic carbon

Soil organic carbon content was determined by Rapid Titration Method (Walkley and Black, 1934). In this method two gram of soil was oxidized with a mixture of potassium dichromate and concentrated sulphuric acid utilizing the heat of dilution of sulphuric acid. Unused potassium dichromate was back-titrated with ferrous ammonium sulphate in presence of diphenylamine indicator.

3.17.2.4 Available nitrogen

Available nitrogen was determined using alkaline potassium permanganate method (Subbiah and Asija, 1956). The procedure involves distilling the soil with alkaline potassium permanganate solution and determining the ammonia liberated by titrating against sulphuric acid (0.02N).

3.17.2.5 Available phosphorus

The Olsen's method (Olsen *et al.*, 1954) was used for determination of available-P in soil. In this method soil was extracted with 0.5 M NaHCO_3 (pH 8.5). Five ml of extract was taken and color was developed by ascorbic acid solution. After waiting for 10 minutes, the intensity of blue color was measured on spectrophotometer at 660 nm.

3.17.2.6 Available potassium

Five gram soil was extracted with neutral normal ammonium acetate solution (pH 7.0) by shaking for 30 minutes. Potassium content in the extract was determined flame photo metrically as given by Jackson (1973).

3.18 Chemical analysis of plant

For chemical analysis of plant samples the plant material were taken at harvest. Samples were cleaned properly by repeated washing followed by 0.1N HCl, solutions. Finally all the samples were subjected to washing by double distilled water. Samples were then dried under shade followed by hot air oven at $60 \pm 1^{\circ}\text{C}$ for 48 hours. After drying samples were weighed and grinded in Willey's Mill as per treatment separately and stored in butters paper covers. Samples were then subjected to chemical analysis for nitrogen, phosphorous, potassium, zinc content.

3.18.1 Nitrogen

Content of N was estimated both in grain as well as in straw by modified Kjeldahal methods as described by Jackson (1973). Total nitrogen content of N in grain and straw was multiplied by the respective dry matter yield to get the total nitrogen uptake by plants.

3.18.2 Phosphorous

Phosphorous content was determined in grain as well as straw by Vandomolybdo phosphoric yellow color method as suggested by Jackson (1973). Total phosphorus content both of grain and straw was multiplied by the production of dry matter of the plant to obtain phosphorus removal ha^{-1} .

3.18.3 Potassium

Potassium was estimated with the help of Flame photometer as described by Jackson (1973). Potassium present in grain and straw were multiplied by their dry matter. The uptake of the entire major nutrient in kg ha^{-1} calculated by using the formula given by Black, (1965).

3.18.4 Estimation of zinc

For estimating the Zn both in grain and straw, ten gram samples were taken and dried in oven at $60 \pm 1^{\circ}\text{C}$ for 48 hours. Samples were then crushed with mortar

and pistal. Out of this only 0.5 gram grinded sample were taken in a test tube and 10 ml diacid ($\text{HNO}_3 + \text{HClO}_4$ in mix of 9:4 ratio) was added. These samples were then transferred to a beaker containing diacid and subjected to digest at low temperature on heater for 8 hours. Thereafter one ml of digested samples were taken in test tube and diluted by adding double distilled water to make it 50 ml in volumetric flask. The concentration of zinc was then estimated by Atomic Absorption Spectrophotometer (AAS) Lindsay and Norvell, (1978).

3.18.5 Nutrient uptake (kg ha^{-1})

Nutrient uptake in grain and straw as well as their total uptake ha^{-1} was calculated taking corresponding yield and nutrient content by using following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient content (\%)} \times \text{yield (qha}^{-1}\text{)}$$

3.19 Estimation of fertilizer use efficiencies

Fertilizer use efficiency of nitrogen and zinc was computed needs under the followings.

3.19.1 Partial factor productivity (PFP)

Partial factor productivity defined as grain production per unit nutrient applied. It is calculated by formula given by Fageria and Baligar, (2003).

$$\text{PFP (kg kg}^{-1}\text{)} = \frac{\text{Grain yield (treated plot)}}{\text{Plant nutrient applied (treated plot)}}$$

3.19.2 Agronomic efficiency (AE)

Agronomy efficiency is the ratio of yield to nutrient supply. It is calculated by using the formula given by Fageria and Baligar, 2003 and Ladha *et al.*, 2005.

$$\text{AE (kg kg}^{-1}\text{)} = \frac{\text{Grain yield (treated plot)} - \text{Grain yield (control plot)}}{\text{Plant nutrient applied (treated plot)}}$$

3.19.3 Physiological efficiency (PE)

Physiological efficiency is representing as the ability of a plant to transport nutrient acquired from fertilizer into economic yield. It is calculated by formula given by Fageria and Baligar, 2003 and Doberman, 2005).

$$PE \text{ (kg kg}^{-1}\text{)} = \frac{\text{Grain yield(treated plot)} - \text{Grain yield(control plot)}}{\text{Nutrient uptake(treated plot)} - \text{Nutrient uptake(control plot)}}$$

3.19.4 Recovery efficiency (RE)

Recovery efficiency is the ratio of plant zinc to per Kg Zn applied and calculated by following formula (Doberman, 2005; ladha *et al.*, 2005)

$$RE = \frac{\text{Nutrient uptake (treated plot)} - \text{Nutrient uptake (control plot)}}{\text{Plant nutrient applied (treated plot)}} \times 100$$

3.19.5 Nutrient harvest index (NHI)

Nutrient harvest index is the ratio of nutrient uptake in grain to total nutrient uptake or defined as portioning of total plant nutrient into grain. Normally, NHI is expressed in percentage and calculated by formula given by Fageria and Baligar, 2003.

$$NHI \text{ (\%)} = \frac{\text{Nutrient accumulated in grain (kg/ha)}}{\text{Nutrient accumulated in above ground dry matter(kg/ha)}}$$

3.20 Economics

The economics of various treatments was computed for the respective years by taking into account the existing price of inputs and produce. The cost for fertilizers, labor and power for performing different operations such as ploughing, weeding, irrigation, harvesting, threshing and winnowing etc., were worked out on per hectare basis prevalent on market price. The cost of cultivation was taken into account for calculating economics of treatments.

3.20.1 Gross return (₹ ha⁻¹)

The yield of rice was converted into gross return in rupees per hectare on the basis of current price of the produce.

3.20.2 Net return (₹ ha⁻¹)

The net return was estimated by using following formula:

$$\text{Net Return (₹ ha}^{-1}\text{)} = \text{Gross return (₹ ha}^{-1}\text{)} - \text{Cost of cultivation (₹ ha}^{-1}\text{)}$$

3.20.3 Output input ratio/benefit cost ratio (B: C) or BCR

The output input ratio was worked out on the basis of net return and cost of cultivation .

$$\text{Benefit cost ratio (B:C)} = \frac{\text{Gross returns (₹ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ha}^{-1}\text{)}}$$

3.21 Statistical analysis

The observations recorded during the course of investigation were tabulated and analyzed statistically to draw a valid conclusion. The data were analyzed as per the standard procedure for “Analysis of Variance” (ANOVA) as described by Gomez and Gomez (1984). The significance of treatments was tested by ‘F’ test (Variance ratio). Standard error of mean (SEm±) was computed in all cases. The difference in the treatment mean were tested by using critical difference (CD) or least significant difference (LSD) at 5% level of probability where ‘F’ test showed significant differences among means by the following formula:

$$\text{C.D.} = \text{S.E. (d)} \times t \text{ at 5\% for error degree of freedom (d.f.).}$$



EXPERIMENTAL FINDINGS

An endeavor has been made in this chapter to assess the “**Phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice**”. The results recorded during the course of investigation were subjected to statistical analysis and the inference drawn along with suitable interpretation has been presented and elucidated through relevant tables and graphs. While describing the results, statistically significant variations have been highlighted in order to compare statistically outstanding treatments in relation to various growth, yield and quality parameters.

4.1 Growth attributes

Progressive crop growth attributes were recorded at different phonological stages of crop *i.e.* 30, 60, 90 DAS and at harvest. The result of experimental variables on growth are described here under, different subhead

4.1.1 Plant height (cm)

Data pertaining to the plant height (cm) recorded at successive growth stages have been presented in the table 4.1.1. In general plant height increase with advancement of crop growth stages and reached to maximum at harvest, irrespective of experimental variability.

Nitrogen

Perusal of data (Table 4.1.1) reveals that plant height was significantly influenced by nitrogen rate at different growth stages. Application of 160 kg N/ha had significant effect on plant at 30, 60, 90 DAS and at harvest, over control & 120 kg N/ha. The maximum plant height (91.02 cm) was recorded at 90 DAS and lowest with control (67.77cm). N₂ recorded 34.31 % higher plant height at 90 DAS as compare to control (N₀).

Zinc

Critical appraisal of data showed (Table 4.1.1) that there were significant variations in plant height at all the growth stages with zinc treatments. Amongst the zinc treatments, 10 kg Zn/ha at basal + 0.3% ZnSO₄ spray at G 45 (late booting) + 0.3% ZnSO₄ spray at G 61 (anthesis) (Z₂) recorded significantly maximum plant height (84.55 cm), whereas minimum plant height (71.18 cm) was recorded with control at 90 DAS. At 30 DAS, the Z₂ was statistically at par with Z₃ & Z₄. At 60, 90 DAS & maturity, Z₂ was statistically at par with Z₁, Z₃ & Z₄ and significant over control.

Nitrogen × Zinc

Nitrogen rate and zinc application failed to interact with each other in increasing the height of plants.

4.1.2 Number of tillers (running m⁻¹)

Nitrogen

Nitrogen rate had significant influence on number of tillers as recorded at 60, 90 DAS and at harvest stages (Table 4.1.2). As the nitrogen rate was increased from 0 kg N ha⁻¹ to 160 kg N ha⁻¹, the number of tillers increased significantly and recorded maximum (99 tillers running m⁻¹) at 60 DAS and thereafter it subsequently decline. Data showed that N₂ produced 89.37 % & 24.97 % higher number of tillers as compare to N₁ & N₀, respectively.

Zinc

Perusal of data (Table 4.1.2) reveal that there were significant variations in number of tillers with different zinc treatments. Maximum no. of tiller (99.33) are recorded with Z₂ at 60 DAS, whereas minimum no. of tiller (71.22) are recorded with control.

Nitrogen × Zinc

The significant interaction (Table 4.1.2 a) was recorded with nitrogen rate and zinc application on tillers count (number running m⁻¹) at harvest stage. At harvest stage, amongst all the combination, N₂Z₂ recorded significantly higher number of tillers (96.67 running m⁻¹).

4.1.3 SPAD value

Nitrogen

Critical assessment of the data (table 4.1.3) revealed that the significantly maximum SPAD value was recorded with 160 kg N ha⁻¹ (N₂) at 30, 60 and 90 DAS as compared to lower nitrogen rate. The maximum SPAD value (35.20) was recorded with 160 kg nitrogen ha⁻¹ and minimum (28.14) with control at 60 DAS. The result reveal that there was 14.63% decline of SPAD value from 60 DAS to 90 DAS with N₂.

Zinc

Critical appraisal of data showed the treatment Z₂ obtained comparatively higher SPAD value as compared to remaining treatments. The maximum SPAD value (32.96) was recorded at 60 DAS with Z₂. However it was statistically at par with Z₁ and Z₃.

Nitrogen × Zinc

Perusal of data revealed that SPAD value was no significantly interact with nitrogen rate and zinc application.

4.1.4 Leaf Area Index (LAI)

Nitrogen

Observation of data (Table 4.1.4) showed that LAI was significantly influenced by nitrogen rate at different growth stages. Nitrogen level 160 kg N/ha (N₂), maintained the superior LAI as compared to other treatments at all the growth stages of observations and recorded significantly maximum LAI (4.47) at 90 DAS.

Zinc

Data clearly indicate from the table that zinc application also significantly influenced the leaf area index at 30, 60 and 90 DAS. Amongst the treatments, Z₄, Z₃ & Z₂ recorded the significantly higher leaf area index at 30, 60 and 90 DAS respectively. However, maximum LAI was recorded by Z₂ at 90 DAS which was statistically at par with Z₃ and Z₄.

Nitrogen × Zinc

The significant interaction (Table 4.1.4 a & b) was recorded with nitrogen rate and zinc application on LAI at 30 & 60 DAS. At 30 DAS, N₂Z₄ found significantly higher LAI (1.27) At 60 DAS, amongst all the combination, N₂Z₃ recorded significantly higher LAI (4.14).

4.1.5 Shoot dry matter accumulation (g)**Nitrogen**

Nitrogen had significant influence on dry matter accumulation (g running m⁻¹) at all the stages of observations (Table 4.1.5). Scrutiny of data showed that significantly maximum dry matter accumulation (235.53g running m⁻¹) was recorded with 160 kg N /ha (N₂) at harvest, followed by 120kg N/ha⁻¹ and control.

Zinc

Critical observation of the data (Table 4.1.5) showed that there were significant variations in dry matter accumulation (g running m⁻¹). Scrutiny of data revealed maximum dry matter accumulation (g running m⁻¹) was recorded with Z₂ during all stages except 30 DAS. The maximum dry matter accumulation (200.78 g running m⁻¹) was recorded at harvest with Z₂ followed by Z₃ and Z₄.

Nitrogen × Zinc

Perusal of data revealed that there was significant interaction between nitrogen and zinc for dry matter accumulation (g running m⁻¹) at all stages except 30 DAS. At 60 DAS, significantly maximum dry matter accumulation was recorded from the N₂Z₂ (Table 4.1.5 a). At 90 DAS, the combination of N₂Z₄ recorded significantly higher dry matter accumulation (g running m⁻¹). At harvest, the combination of N₂Z₄ recorded significantly higher dry matter accumulation (g running m⁻¹) which was at par with and N₂Z₂ and N₂Z₃ (Table 4.1.5 b).

4.1.6 Root dry matter accumulation (g)**Nitrogen**

Nitrogen had significant influence on dry matter accumulation (g running m⁻¹) at all the stages of observations (Table 4.1.6). Scrutiny of data showed that

significantly maximum dry matter accumulation ($83.70 \text{ g running m}^{-1}$) was recorded with 160 kg N/ha (N_2) at 90 DAS, followed by 120 kg N/ha^{-1} and control.

Zinc

Critical observation of the data (Table 4.1.6) showed that there were significant variations in dry matter accumulation (g running m^{-1}). The maximum dry matter accumulation ($78.43, 75.09 \text{ g running m}^{-1}$) was recorded at 90 DAS and harvest with Z_3 .

Nitrogen $\times$ Zinc

Perusal of data revealed that there was significant interaction between nitrogen and zinc for dry matter accumulation (g running m^{-1}) at 30 and 60 DAS. At 30 DAS, significantly maximum dry matter accumulation was recorded from the N_2Z_1 (Table 4.1.6a). At 90 DAS, the combination of N_2Z_4 recorded significantly higher dry matter accumulation (g running m^{-1}).

4.1.7 Crop growth rate ($\text{g running m}^{-1}\text{day}^{-1}$)

Nitrogen

Critical appraisal of the data (Table 4.1.7) showed that maximum crop growth rate was recorded with 160 kg N/ha (N_2), at 30, 60 and 90 DAS. The maximum CGR (5.199 g) was recorded with 160 kg N/ha at 90 DAS.

Zinc

Critical study of the data reveal that zinc application affects crop growth rate and maximum ($4.664 \text{ g running m}^{-1} \text{ day}^{-1}$) was recorded with Z_2 at 90 DAS. However lowest ($0.349 \text{ g running m}^{-1} \text{ day}^{-1}$) crop growth rate was recorded with control (Z_0) at 30 DAS.

Nitrogen $\times$ Zinc

Critical appraisal of the data (Table 4.1.7 a&b) showed that the nitrogen rate and zinc application was interact to each other at 60 and 90 DAS. Maximum crop growth rate ($6.66 \text{ g running m}^{-1}\text{day}^{-1}$) was recorded with $160 \text{ kg nitrogen/ha} + 10 \text{ kg ZnSo}_4/\text{ha}$ at Basel $+0.25\%$ ZnSo_4 spray at G 51 (tip of inflorescence emerged)

+0.25% ZnSo₄ spray at G 73 (early milk) (N₂Z₄). However the lowest (0.80g running m⁻¹ day⁻¹) crop growth rate was recorded with control (N₀Z₀)(Table 4.1.7a) at 60 DAS.

4.1.8 Relative growth rate (g running m⁻¹day⁻¹)

Nitrogen

Critical appraisal of the data (Table 4.1.8) showed that maximum relative growth rate was recorded with 160 kg N /ha (N₂), at 30, 60 and 90 DAS. The maximum RGR (1.158 g) was recorded with 160 kg N /ha at 60 DAS.

Zinc

Critical study of the data reveal that zinc application affects crop growth rate and maximum (1.148 g running m⁻¹ day⁻¹) was recorded with Z₂ at 90 DAS. However lowest (0.152 g running m⁻¹ day⁻¹) crop growth rate was recorded with control (Z₀) at 30 DAS.

Nitrogen × Zinc

Critical appraisal of the data (Table 4.1.8 a&b) showed that the nitrogen rate and zinc application was interact to each other at 60 and 90 DAS. Maximum relative growth rate (1.69 g running m⁻¹ day⁻¹) was recorded with (N₂Z₂) at 60 DAS. However the lowest (0.22 g running m⁻¹ day⁻¹) crop growth rate was recorded with control (N₀Z₀) (Table 4.1.8 a) at 60 DAS.

4.2 Yield attributes

4.2.1 Effective tillers running m⁻¹

Nitrogen

Perusal of the data (Table 4.2.1) showed that the maximum effective tillers (71.07 per running m⁻¹) was recorded with 160 kg N/ha (N₂) which was significantly higher than all remaining treatments. However the application of 120 kg N ha⁻¹(N₁) recorded significantly maximum effective tillers then control (N₀).

Zinc

Critical observation of the data showed (Table 4.2.1) that the highest effective tillers at harvest ($66.89 \text{ running m}^{-1}$) was recorded with Z_2 followed Z_4 , Z_3 , Z_1 and control (Z_0).

Nitrogen $\times$ Zinc

The observation of the data (Table 4.2.1 a) revealed that significant interaction effect between nitrogen rate and zinc application was recorded and significantly maximum number of effective tiller running m^{-1} (96.67) was recorded with $160 \text{ kg N/ha} + 10 \text{ kg ZnSo}$ at Basel + $0.3\% \text{ ZnSo}_4$ spray at g 45 (late booting) + $0.3\% \text{ ZnSo}_4$ spray at G 61 (anthesis) (N_2Z_2) at harvesting.

4.2.2 Panicle length (cm)**Nitrogen**

Critical appraisal of data (Table 4.2.1) showed that highest panicle length (23.87 cm) was recorded with 160 kg N/ha (N_2). However, the panicle length with 160 kg N ha^{-1} (N_2) which found at par with 120 kg n ha^{-1} (N_1).

Zinc

Critical observation of the data (Table 4.2.1) showed that zinc application had no significant effect on panicle length.

Nitrogen $\times$ Zinc

Perusal of data revealed that panicle length was no significantly interact with nitrogen rate and zinc application.

4.2.3 Grains panicle⁻¹**Nitrogen**

Critical appraisal of data (Table 4.2.1) showed that nitrogen application had significant effect on grains per panicle. Significantly maximum grains per panicle (112.67) were recorded with 160 kg N/ha (N_2), followed by 120 and 0 kg N ha^{-1} .

Zinc

Perusal of data in Table (4.2.1) revealed that application of zinc had significant effect on grains per panicle. Highest grain per panicle (105.89) was found with Z₂ which at par with Z₃ and Z₄.

Nitrogen × Zinc

The data in (Table 4.2.1 b) showed that nitrogen and zinc interact positively to grain per panicle. Highest grain per panicle (124.33) was found with N₂Z₃, which was at par with and N₂Z₂ and N₂Z₄.

4.2.4 Panicle weight (g)**Nitrogen**

Perusal of the data (Table 4.2.1) showed that nitrogen application affect the panicle weight and recorded maximum panicle weight (2.76 gram) with 160 kg nitrogen/ha (N₂), which was significant higher than remaining treatments. However, application of 120 kg N/ha⁻¹ was significantly higher over control.

Zinc

Critical examination of data (Table 4.2.1) revealed that application of zinc significantly and positive effect on panicle weight. Maximum panicle weight (2.57 g) was recorded with Z₂. This was statistically at par with Z₁, Z₃ and Z₄.

Nitrogen × Zinc

The data in (Table 4.2.1 c) showed that nitrogen and zinc interact positively to increase the panicle weight. Maximum panicle weight (3.13 g) was recorded with N₂Z₃ which was significantly higher than all remaining treatments. However the value of N₂Z₂, N₂Z₀, and N₁Z₂ was statistically at par with N₃Z₃.

4.2.5 Test weight (g)**Nitrogen**

Perusal of the data (Table 4.2.1) showed that nitrogen application had significantly positive effect on test weight. Significantly maximum test weight (23.53 g) was recorded with 160 kg N/ha (N₂), which was significantly higher than

remaining treatment. However application of 120 kg N/ha also found significant higher than control.

Zinc

Screening of data revealed (Table 4.2.1 d) that test weight was increased by application of zinc spray at different stages. The higher test weight (23.66 g) was found with Z_2 . However, the test weight of 21.29 g was obtained due to Z_4 , which was statistically at par with Z_3 and Z_1 .

4.2.6 Grain yield (kg ha⁻¹)

Nitrogen

Critical observation of the data (Table 4.2.2) showed that nitrogen rate positively increased the grain yield. Significantly higher grain yield (3817.71 kg/ha) with 160 kg N/ha (N_2), which was significantly higher remaining treatments. However, the grain yield of 2801.96 kg/ha was recorded with application of 120 kg N/ha respectively, over control (1957.52 kg/ha).

Zinc

Critical appraisal of data (Table 4.2.2) showed that grain yield of crop was influenced by zinc application at different stages. Among treatments, highest grain yield (3442.59 kg ha⁻¹) was obtained with Z_2 , which was significantly higher than all remaining treatments. However the grain yields of 3039.40, 2985.84 and 2851.93 kg/ha was obtained with Z_4 , Z_3 and Z_1 respectively, that was significant higher control (1975.56 kg ha⁻¹).

Nitrogen × Zinc

The observation showed (Table 4.2.2 a) that the grain yield was positively affected by interactive effect of nitrogen and zinc. Significant interaction between nitrogen and zinc was observed and recorded highest grain yield (4612.08 kg ha⁻¹) with N_2Z_2 , which was statistically at par with N_2Z_4 and significantly higher than remaining treatments.

4.2.7 Straw yield (kg ha⁻¹)

Nitrogen

Perusal of the data (Table 4.2.2) revealed that the highest straw yield of 6384.94 kg/ha was obtained with 160 kg N/ha (N₂) which was significantly higher than 120 kg N ha⁻¹ and control. Data reveal that there was 41.18% higher straw yield with N₂ as compared to control.

Zinc

Critical observation of the data indicates that the maximum straw yield (5658.50 kg) was obtained with Z₃, being at par with all treatment except control.

Nitrogen × Zinc

The observation showed (Table 4.2.2 b) that the straw yield was positively affected by interactive effect of nitrogen and zinc. Significant interaction between nitrogen and zinc was observed and recorded highest straw yield (6916.63 kg/ha) with N₂Z₂, which was statistically at par with N₂Z₄, N₂Z₃ and N₂Z₁.

4.2.8 Biological yield (kg ha⁻¹)

Nitrogen

The observation (Table 4.2.2) showed significantly maximum biological yield of 10202.98 kg ha⁻¹ obtained with 160 kg N/ha (N₂) that was significantly higher over lower rate of nitrogen. However, the biological yield of 7854.07 kg/ha due to 120 kg N/ha (N₁), was significant higher over control (N₀).

Zinc

Perusal of the data (Table 4.2.2) showed that biological yield was affected by application of zinc sulphate at different stages. Significantly maximum biological yield (9010.17 kg ha⁻¹) was found with Z₂, which was higher than rest of the treatments. However, the value of Z₂ was found statistically at par with all treatment except control.

Nitrogen × Zinc

The observation showed (Table 4.2.2 c) that the biological yield was positively affected by interactive effect of nitrogen and zinc. Significant interaction between nitrogen and zinc was observed and recorded highest biological yield (11528.70 kg/ha) with N₂Z₂, which was statistically at par with N₂Z₄, N₂Z₃ and N₂Z₁.

4.2.9 Harvest Index (%)**Nitrogen**

The observation (Table 4.2.2) showed that there was significant variation on harvest index due to various nitrogen management. Higher value of harvest index (37.29%) was found with 160kgN/ha (N₂) and lowest value of harvest index (30.16%) was found with control (N₀).

Zinc

Data clearly indicate that there was significant variation in harvest index due to the various zinc management. Highest harvest index (36.83%) was reported with Z₂ and lowest (29.92%) with control (Z₀).

4.3 Nutrient content and uptake**4.3.1 Nitrogen content in grain (%)****Nitrogen**

A critical observation of the data (table 4.3.1) showed that the maximum nitrogen content (1.16%) in grain was recorded with 160 kg N/ha (N₂) and it was significantly higher than all remaining treatments. However the lowest value (0.86 %) was found with control (N₀).

Zinc

Critical appraisal of data (table 4.3.1) showed that significantly maximum nitrogen content (1.32%) in grain was recorded with Z₄. However it was statistically at par with Z₂. The lowest value (0.89 %) was recorded with control (Z₀).

Nitrogen × Zinc

The critical observation of the data (table 4.3.1 a) showed that the maximum nitrogen content (2.03%) in grain was recorded with 160 kg N/ha + 0.3% ZnSO₄spray at dough stage (N₂Z₃) and it was significantly higher than all other treatment. However the lowest value (0.70%) was found with control (N₀Z₀).

4.3.2 Phosphorus content in grain (%)**Nitrogen**

Critical appraisal of data (table 4.3.1) showed that significantly maximum phosphorus (0.26%) content in grain was recorded N₂. However it was at par with N₁. While, lowest value (0.21%) was found with control (N₀).

Zinc

Perusal of the data showed that the maximum phosphorus content in grain (0.25 %) was found with Z₃. However the value of Z₂ and Z₄ was statistically at par with Z₁ and the lowest value (0.214%) was found with control (Z₀).

Nitrogen × Zinc

The critical observation of the data (table 4.3.1 b) showed that the maximum phosphorus content in grain (0.26%) was found with 160 kg nitrogen/ha + 0.3% ZnSO₄spray at anthesis (N₂Z₁). However the all remaining value found significantly comparable with N₂Z₁except control (N₀Z₀).

4.3.3 Potassium content in grain (%)**Nitrogen**

The observation (table 4.3.1) showed that significantly maximum potassium content in grain (0.29%) was found with N₁ followed by N₂ and lowest value (0.26%) was found with N₀.

Zinc

Critical appraisal of the data (table 4.3.1) reveals that there was no significant variation found amongst all treatments but treatment Z₂ was recorded maximum potassium content (0.29%) in grain and lowest potassium (0.24%) content in grain was found with (Z₀).

4.3.4 Zinc content in grain (mg kg⁻¹)

Nitrogen

Perusal of the data (table 4.3.1) showed that the maximum zinc content in grain (38.92 mg kg⁻¹) was found with N₂ and it was significantly higher than other remaining treatments.

Zinc

Critical appraisal of the data (table 4.3.1) reveals that the maximum zinc content (39.29 mg kg⁻¹) in grain was found with Z₄, which is significantly higher than all treatment.

Nitrogen × Zinc

The critical observation of the data (Table 4.3.1 d) showed that the maximum zinc content in grain (51.57 mg) was found with 160 kg N/ha + 0.3% ZnSO₄ spray at dough stage (N₂Z₃), which was significantly higher than all remaining treatments.

4.3.5 Nitrogen content in straw (%)

Nitrogen

A critical observation of the data (table 4.3.1) showed that the significantly maximum nitrogen content in straw (0.58%) was recorded with treatment N₂ followed by N₂ and N₁. However, application of nitrogen (N₁) recorded nitrogen content of 0.49% and significant over control (.35%).

Zinc

Critical appraisal of data (table 4.3.1) showed that significantly maximum nitrogen content in straw (0.51%) was found Z₄ but statistically at par with Z₂. While, lowest value was found with Z₀ (39%).

4.3.6 Phosphorus content in straw (%)

Nitrogen

The observation (table 4.3.1) showed that no any treatment was found significantly difference. However the maximum phosphorus content in straw

(0.083%) was recorded with N₃ and lowest value (0.078%) was found with control (N₀).

Zinc

The observation showed that there was no significant variation was recorded with phosphorus content in straw. However, maximum phosphorus content (0.084%) was recorded with Z₁ and lowest value was recorded with Z₀ (0.077%).

4.3.7 Potassium content in straw (%)

Nitrogen

The observation (table 4.3.1) showed that there was no significant value found among all treatments. However the maximum potassium content (1.25%) in straw was found with 90 kg N/ha (N₁) and lowest potassium content (1.209%) in straw was found with control (N₀).

Zinc

Critical appraisal of the data (table 4.3.1) revealed that no treatment was found significantly different among all treatment but treatment Z₂ was found maximum potassium content (1.27%) in straw and lowest potassium content (1.169%) in straw was observed with Z₀.

4.3.8 Zinc content in straw (mg kg⁻¹)

Nitrogen

Perusal of the data (Table 4.3.1) showed that the maximum zinc content in straw (71.45 mg) was found with N₂ which is significant over rest of the treatments. However the value of N₁ and N₀ was statistically at par.

Zinc

Critical appraisal of the data (Table 4.3.1) revealed that the maximum zinc content (78.67 mg) in straw was found with Z₄ treatment being at par with Z₃, which is significantly higher than all remaining treatment.

4.3.9 Nitrogen uptake in grain (kg ha⁻¹)

Nitrogen

The data presented (Table 4.3.2) Revealed that significantly maximum nitrogen uptake (60.17 kg ha⁻¹) by grain was recorded with the application of 160 kg nitrogen/ha (N₁) and followed by 120, 90 and 0 kg N ha⁻¹.

Zinc

Application of Z₂ treatment being on par to Z₄, recorded significantly maximum nitrogen uptake (47.97 kg ha⁻¹) which is significant over rest of the treatments. However, the value of Z₁ and Z₃ treatment was at par with each other and significant over Z₀.

Nitrogen × Zinc

The data (Table 4.3.2 a) clearly indicated that nitrogen and zinc interaction with N₂Z₄ recorded significantly maximum nitrogen uptake (79.91 kg ha⁻¹) and was statistically at par with N₂Z₂. However, the lowest N uptake (11.42 kg ha⁻¹) obtained from control (N₀Z₀).

4.3.10 Nitrogen uptake in straw (kg ha⁻¹)

Nitrogen

Application of 160 kg N ha⁻¹(N₂) resulted in significantly maximum nitrogen uptake (37.32 kg N ha⁻¹) in straw which was significant over rest of the treatments. While, lowest value (16. 0 kg ha⁻¹) was obtained with control (N₀).

Zinc

Application of Z₂ treatment recorded significantly maximum nitrogen uptake in straw (27.94 kg ha⁻¹) and significant statistically only as compared to control but at par to rest of the treatments.

Nitrogen × Zinc

The data (Table 4.3.2 b) indicated that combined application of N₂Z₂ significantly recorded maximum nitrogen uptake (44.61 kg ha⁻¹) by straw and was statistically at par with N₂Z₂, N₂Z₄, N₂Z₃, and N₂Z₁. However, the lowest N uptake (10.07 kg ha⁻¹) obtained from control (N₀Z₀).

4.3.11 Phosphorus uptake in grain (kg ha⁻¹)

Nitrogen

Critical appraisal of the data (table 4.3.2) revealed that the maximum P uptake (9.66 kg ha⁻¹) in grain was obtained from N₂, and significant over control and N₂ treatment. However, N₁ treatment recorded 6.73 kg ha⁻¹ p uptake by grain and found significant over control (N₀).

Zinc

Table 4.3.2 showed that phosphorus uptake (8.19 kg ha⁻¹) by grain was found maximum with Z₂. However it was at par with all Zinc treatments except Z₀. While, lowest phosphorus uptake (4.133 kg ha⁻¹) in grain was found with Z₀ treatment.

4.3.12 Phosphorus uptake in straw (kg ha⁻¹)

Nitrogen

The observation of data (table 4.3.2) showed that significantly maximum phosphorus uptake in straw (5.261 kg ha⁻¹) was found with N₂, however, it was statistically at par with N₁.

Zinc

The data in table 4.3.2 showed that highest phosphorus uptake (4.65 kg ha⁻¹) was recorded with Z₁ and statistically at par to rest of the treatments. However, lowest phosphorus uptake in straw was found with control (Z₀).

4.3.13 Potassium uptake in grain (kg ha⁻¹)

Nitrogen

Critical study of the data showed that maximum potassium uptake (10.54 kg ha⁻¹) in grain was obtained with 160 kg N/ha (N₂) and significant over rest of the treatments.

Zinc

Perusal of data (table 4.3.2) showed that significantly maximum potassium uptake in grain was observed with Z₂ which is significant over all treatments and

lowest value was found with control (Z_0). However, Z_1 , Z_3 and Z_4 at par to each other but significant to control.

4.3.14 Potassium uptake in straw (kg ha^{-1})

Nitrogen

Perusal of data (table 4.3.2) showed that application of 160 kg N ha^{-1} (N_2) recorded significantly maximum potassium uptake (80.07 kg ha^{-1}) in straw as compared to control. However, application of N_1 treatment significantly increased the potassium uptake by straw relative to control.

Zinc

Perusal of the data showed (4.3.2) that the highest potassium uptake (70.98 kg ha^{-1}) in straw obtained with Z_2 which was statistically at par with all other treatments except in control.

Nitrogen $\times$ Zinc

The evaluation of data (Table 4.3.2 c) revealed that interactive effect of nitrogen and zinc affected K uptake by straw. Maximum K uptake (90.43 kg ha^{-1}) by straw was recorded with N_2Z_1 being at par with N_2Z_2 , N_2Z_3 and N_2Z_4 and significant over rest of the treatments. While, lowest K uptake (48.75 kg ha^{-1}) by straw was obtained with control (N_0Z_0).

Zinc uptake in grain (kg ha^{-1})

Nitrogen

Critical examination of data (Table 4.3.2) showed that maximum zinc uptake (0.155 kg ha^{-1}) in grain was obtained with 160 kg N/ha (N_2) and it was significantly higher than all remaining treatment. However the lowest uptake value was recorded (0.042 kg ha^{-1}) with control (N_0).

Zinc

Critical examination of data revealed that the maximum zinc uptake (0.130 kg ha^{-1}) in grain was recorded with Z_4 and it was significantly higher than remaining treatment.

Nitrogen × Zinc

The data (table 4.3.2 d) showed that significantly maximum zinc uptake (0.23 kg ha^{-1}) by grain recorded with N_2Z_4 which is significantly higher than rest of all treatment combinations. However the lowest zinc uptake (0.03) was obtained with control (N_0Z_0).

4.3.16 Zinc uptake in straw (kg ha^{-1})**Nitrogen**

Critical examination of data (table 4.3.2) revealed that the maximum zinc uptake (0.466 kg ha^{-1}) in straw obtained with 160 kg N/ha (N_2) and it was significantly higher than rest of the treatment.

Zinc

Critical examination of data (table 4.3.2) revealed that highest zinc uptake (0.483 kg ha^{-1}) in straw was recorded with Z_4 treatment. However it was found statistically at par to Z_2 and Z_3 . While, lowest value (0.176 kg ha^{-1}) was observed in control (Z_0).

4.3.17 Total nitrogen uptake (kg ha^{-1})**Nitrogen**

Perusal of data showed (table 4.3.3) that significantly maximum nitrogen uptake by rice plant (97.51 kg ha^{-1}) was recorded from the application of 160 kg N/ha (N_2) over rest of all treatments. However, lowest nitrogen uptake (33.03 kg ha^{-1}) was recorded with control.

Zinc

Perusal of the data (Table 4.3.3) revealed that highest nitrogen uptake (77.21 kg/ha) by rice plant was observed with Z_2 , and significant over all treatments except Z_4 . However, the value of Z_1 was found statistically at par with Z_3 and lowest value (36.00) was obtained with control (Z_0).

Nitrogen × Zinc

The data (table 4.3.3 a) indicated that interactive effect of nitrogen and zinc management significantly improved the N uptake by crop plants. Maximum nitrogen uptake ($122.35 \text{ kg ha}^{-1}$) by crop was observed with combined application of N_2Z_4 , which was statistically at par with N_2Z_2 and significantly higher than all other treatment combinations. However, lowest N uptake (25.48 kg ha^{-1}) by crop was obtained from N_0Z_0 .

4.3.18 Total phosphorus uptake (kg ha^{-1})**Nitrogen**

Critical study of the data (Table 4.3.3) showed that maximum phosphorus uptake (14.92 kg ha^{-1}) was recorded with N_2 , and it was found significant over all treatments and the lowest phosphorus uptake (7.65 kg/ha) was obtained with control (N_0).

Zinc

Perusal of the data (Table 4.3.3) showed that the highest phosphorus uptake (12.77 kg ha^{-1}) was recorded with Z_2 . However it was found statistically at par with remaining treatments except Z_0 and lowest phosphorus uptake (7.684) was obtained with control (Z_0).

4.3.19 Total potassium uptake (kg ha^{-1})**Nitrogen**

Critical evaluation of the data (Table 4.3.3) revealed that maximum potassium uptake (90.61 kg ha^{-1}) was recorded N_2 which is highly significant over all remaining treatments.

Zinc

Perusal of the data (Table 4.3.3) showed that the highest zinc uptake (81.08 kg ha^{-1}) was recorded with Z_2 and significant over rest of the treatments. Whereas, lowest potassium uptake (58.06 kg ha^{-1}) was obtained in control (Z_0).

Nitrogen × Zinc

The data (table 4.3.3 b) revealed that maximum nitrogen and zinc interaction effect was recorded with N_2Z_1 , which resulted in significantly maximum potassium uptake ($101.39 \text{ kg ha}^{-1}$) over remaining treatment but at par to N_2Z_2 , N_2Z_3 and N_2Z_4 . However, lowest value of these was recorded in control treatment (N_0Z_0).

4.3.20 Total zinc uptake (kg ha^{-1})**Nitrogen**

Critical examination of the data (table 4.3.3) showed that maximum Zn uptake (0.622 kg ha^{-1}) was observed with N_2 and it was found significantly higher than remaining treatment. However the lowest zinc uptake (0.296 kg/ha) was obtained with control (N_0).

Zinc

The evaluation of data (table 4.3.3) indicated that highest Zn uptake (0.569 kg ha^{-1}) by crop was recorded with Z_4 but statistically at par with Z_3 and significantly higher than all remaining treatment. While, lowest zinc (0.217 kg/ha) uptake was recorded with control (Z_0).

Nitrogen × Zinc

Analysis of data (table 4.3.3 c) revealed that combined application of nitrogen rate and zinc had significant effect on zinc uptake by crop. Maximum values of these were recorded with N_2Z_4 and N_2Z_3 combination (0.81 and 0.73 kg ha^{-1}) which were significant as compared to all other treatment combination. While, lowest zinc uptake (0.15 kg ha^{-1}) by crop was noted with control (N_0Z_0).

4.4 Fertilization on efficiency**4.4.1 Partial factor productivity ($\text{kg grain kg}^{-1} \text{ N}$) of nitrogen****Nitrogen**

A study of data on partial factor productivity (table 4.4.1) indicated that maximum partial factor productivity ($23.86 \text{ kg grain kg}^{-1}$) of nitrogen was recorded with N_2 followed by N_1 . However, a value of partial factor productivity was declined with increasing rate of nitrogen.

Zinc

Further data (table 4.4.1) indicated that the maximum (486.21 kg grain kg⁻¹) partial factor productivity of nitrogen was recorded with Z₂, which is significantly different than other zinc treatments. However, the value of partial factor productivity with Z₄, Z₃ and Z₁ was at with each other but significant over control. While, lowest value of partial factor productivity (10.39 kg grain kg⁻¹) was recorded with control.

Nitrogen × Zinc

Critical examination of the data (table 4.4.1 a) showed that significantly maximum (28.83 and 28.74 kg grain kg⁻¹ N) partial factor productivity of nitrogen was recorded with N₂Z₂ and N₁Z₂ and lowest value was recorded with N₀Z₀, N₀Z₁, N₀Z₂, N₀Z₃, N₀Z₄ and N₀Z₄.

4.4.1b Partial factor productivity (kg grain kg⁻¹ Zn) of zinc**Nitrogen**

The partial factor productivity found maximum (424.10 kg grain kg⁻¹ Zn) with N₂ and which was significantly different from all other nitrogen treatments. However the lowest (209.38 kg grain kg⁻¹ Zn) partial factor productivity found with control (N₀).

Zinc

The observations (table 4.4.2) clearly indicated that maximum partial factor productivity (498.47 kg grain/kg of zinc) was recorded with Z₃ and which is significantly higher than all remaining treatments except Z₁. However, the lowest value (0 kg grain/kg of zinc) was found with control (Z₀).

Nitrogen × Zinc

Critical appraisal of the data (table 4.4.2 a) showed that significantly maximum partial factor productivity (658.32 kg grain/kg) of zinc was recorded with N₂Z₁ which is a significantly different among other treatment combination except N₂Z₃.and lowest was obtained with N₀Z₀, N₁Z₀ and N₂Z₀.

4.4.2 Agronomic efficiency (kg grain increase kg⁻¹ N) of nitrogen

Nitrogen

Critical appraisal of data (Table 4.4.1) showed that significantly maximum agronomic efficiency of nitrogen (8.63 kg grain increase kg⁻¹ N) was found with application of N₂ which is significant over N₁ and control.

Zinc

Critical observation of the data (Table 4.4.1) indicated that application of Z₁ treatment resulted in significantly better agronomic efficiency of N (11.327 kg grain increase kg⁻¹ Zn) over rest of the treatments. However the value of Z₄ and Z₃ was statistically at par with Z₁.

Nitrogen × Zinc

Critical appraisal of the data (table 4.4.1 b) showed that significantly maximum agronomic efficiency (18.72) of nitrogen was recorded with N₂Z₂ treatment but being at par to N₁Z₂, N₂Z₁ and N₂Z₃, which is a significantly over rest of other treatment combination.

Agronomic efficiency (kg grain kg⁻¹) of zinc

Nitrogen

An examination of data (Table 4.4.2) showed that significantly maximum agronomic efficiency of zinc (258.07 kg grain increase kg⁻¹ N) was found with application of N₂ which is significant over N₁ and control.

Zinc

Critical observation of the data (Table 4.4.2) indicated that application of Z₃ treatment resulted in significantly better agronomic efficiency of N (228.485 kg grain increase kg⁻¹ Zn) over rest of the treatments. However the value of Z₃ was statistically at par with Z₁.

Nitrogen × Zinc

Critical appraisal of the data (table 4.4.2 b) showed that significantly maximum agronomic efficiency (388.34 kg grain/kg) of zinc was recorded with N₂Z₁

which is significant than all other treatments except N_2Z_3 and lowest was obtained with N_0Z_0 , N_1Z_0 and N_2Z_0 .

4.4.3 Recovery efficiency of nitrogen (%)

Nitrogen

Critical appraisal of data (table 4.4.1) revealed that the application of N_2 resulted in significantly maximum recovery efficiency (45.02%) of N was recorded and which was significantly higher among remaining treatment and lowest value was found with control (N_0).

Zinc

Perusal of the data (table 4.4.1) showed that the highest recovery efficiency of nitrogen (32.69%) was recorded with Z_2 and which is significantly higher than all remaining treatments. However, value of recovery efficiency with Z_4 , Z_3 and Z_1 was at par to each other.

Nitrogen $\times$ Zinc

Critical examination of the data (table 4.4.1 c) showed that significantly maximum recovery efficiency (60.54%) of nitrogen was recorded when combined N_2Z_4 applied and significantly higher than rest of the treatments. However, lowest value was observed with N_0Z_0 , N_0Z_1 , N_0Z_2 , N_0Z_3 and N_0Z_4 .

Recovery efficiency of zinc (%)

Nitrogen

Critical appraisal of data (table 4.4.2) showed that the application of N_2 resulted in significantly maximum recovery efficiency (5.69%) of zinc was recorded and which was significantly higher among remaining treatment and lowest value was found with control (N_0).

Zinc

Perusal of the data (table 4.4.2) showed that the highest recovery efficiency of zinc (6.23%) was recorded with Z_3 and which is significantly higher than all remaining treatments.

Nitrogen × Zinc

Critical appraisal of the data (table 4.4.2 c) showed that significantly maximum recovery efficiency (9.71%) of zinc was recorded with N_2Z_3 which is significant than other treatments.

4.4.4 Nitrogen harvest index (%)**Nitrogen**

Critical evaluation of data (Table 4.4.1) revealed that significantly maximum nitrogen harvest index (60.54%) was observed with application of N_2 . However, all remaining treatments recorded statistically at par with each other.

Zinc

Further critical appraisal of data (table 4.4.1) showed that significantly maximum N harvest index (29.79%) was recorded with Z_2 and the lowest N harvest index recorded with Z_0 .

Zinc harvest index (%)**Nitrogen**

Critical appraisal of data (Table 4.4.2) showed that significantly maximum zinc harvest index (24.32%) was observed with application of N_2 . However, it was at par with N_2 .

Zinc

Critical appraisal of data (table 4.4.2) showed that significantly maximum zinc harvest index (21.66%) was recorded with Z_2 and the lowest zinc harvest index recorded with Z_0 .

4.4.5 Physiological efficiency (kg grain kg⁻¹) of nitrogen**Nitrogen**

The critical observation of the data (table 4.4.1) indicated that application of N_2 produce maximum physiological efficiency (39.70 kg grain kg⁻¹ N uptake) of nitrogen. However, there was no significant difference between all treatments.

Zinc

Critical appraisal of data (table 4.4.1) showed that significantly highest physiological efficiency (44.80 and 43.20 kg grain kg⁻¹ of zinc uptake) of nitrogen was recorded with Z₃ and Z₂ and it was significantly higher than all remaining treatments.

Physiological efficiency (kg grain kg⁻¹) of zinc**Nitrogen**

The critical observation of the data indicated that application of N₁ produce significantly maximum physiological efficiency (5171.32 kg grain kg⁻¹ Zn uptake) of zinc. However, it was found statistically at par with N₁ except control N₀.

Zinc

Critical appraisal of data (table 4.4.2) showed that highest physiological efficiency (9576.13 kg grain kg⁻¹ of zinc uptake) of zinc was recorded with Z₂ and it was significantly higher than all remaining treatments except Z₁.

4.5 Quality parameters**4.5.1 Protein contain (%)****Nitrogen**

Critical appraisal of data (Table 4.5.1) showed that the maximum protein content (9.48%) in grain was recorded with N₂ and it was significantly higher than all remaining treatment. However the lowest protein (5.35%) content was obtained with control (N₀).

Zinc

Critical appraisal of data (Table 4.5.1) indicated that significantly highest protein content (8.27%) in grain was found with Z₄. However, the value of Z₄ was recorded statistically at par with Z₂ and significant over all other treatments.

Nitrogen × Zinc

The evaluation of data (Table 4.5.1 a) showed that protein content in grain affected by interactive effect of nitrogen and zinc. Significantly maximum nitrogen and zinc interaction effect on protein content (11.31%) was recorded with N₂Z₄ which is higher than rest of other treatments but was on par to N₂Z₂ and N₂Z₃.

4.5.2 Protein yield (kg/ha)

Nitrogen

Critical examination of the data (Table 4.5.1) showed that the maximum protein yield (376.05 kg/ha) was obtained with N₂ and it was significantly higher than all remaining treatment. However, the lowest value (106.40 kg /ha) was found with control (N₀).

Zinc

Critical appraisal of data (Table 4.5.1) showed that significantly maximum protein yield (333.53 kg/ha) was obtained with Z₂ and significant over rest of the treatments..

Nitrogen × Zinc

The data (Table 4.5.1 b) Indicated that maximum nitrogen and zinc interaction effect was obtained N₂Z₄, which was at par with N₂Z₂ and N₂Z₃ and significantly higher than all remaining treatments.

4.6 Economics

4.6.1 Cost of cultivation

Nitrogen

Critical study of the data (Table 4.6.1) showed that the cost of cultivation was recorded maximum (30606.18 ₹ha⁻¹) with 160kg N/ha (N₂) and lowest (28727.95 ₹ ha⁻¹) with control (N₀).

Zinc

Perusal of the data (Table 4.6.1) clearly indicated that the cost of cultivation was recorded maximum (30195.59 ₹ha⁻¹) with Z₂ and lowest with control (29175.59 ₹ha⁻¹).

4.6.2 Gross return

Nitrogen

Critical observation of the data (Table 4.6.1) showed that significantly maximum gross return (79231.12 ₹ha⁻¹) obtained with N₂ which was significantly higher than N₁ and control treatment. While, lowest gross return (44996.10 ₹ha⁻¹) was obtained from control (N₀).

Zinc

The further data (Table 4.6.1) indicated that highest gross return (70781.12 ₹ha⁻¹) was obtained with Z₂ which is significantly more than all other treatment. While, lowest gross return (45420.64 ₹ha⁻¹) was found in Z₀ treatment.

4.6.3 Net return**Nitrogen**

Similarly like gross return the net return also found significantly maximum (48624.94 ₹ha⁻¹) with N₂ and followed by N₁. But lowest net return (16268.15 ₹ha⁻¹) obtained from control (N₀).

Zinc

Perusal of the data (table 4.6.1) revealed that application of Z₂ gave significantly higher net return (40585.52 ₹ha⁻¹) which is higher than rest of the treatments. While, lowest net return (16245.05 ₹ha⁻¹) found with control (Z₀).

4.6.3 B:C ratio**Nitrogen**

The analysis of the data (Table 4.6.1) showed that application of N₂ resulted in significantly maximum benefit cost ratio (1.58) as compared to all other treatments. However, lowest benefit cost ratio (0.57) was noted in control (N₀).

Zinc

Perusal of the data (Table 4.6.1) revealed that application Z₂ significantly gave more benefit cost ratio (1.33) in comparison to other treatments. Lower benefit cost ratio (0.55) obtained in control treatment (Z₀).



Table 4.1.1: Effect of nitrogen and zinc scheduling on plant height (cm)

Treatments	Plant height (cm)			
	30 DAS	60DAS	90 DAS	Harvest
Nitrogen rate				
N ₀	37.18	51.33	67.77	67.62
N ₁	47.02	67.33	80.62	80.06
N ₂	53.80	75.11	91.02	90.20
SEm ±	1.63	1.80	2.16	2.06
CD (P=0.05)	4.72	5.23	6.25	5.98
Scheduling of Zinc				
Z ₀	39.19	57.88	71.18	70.96
Z ₁	44.82	63.03	76.92	76.66
Z ₂	50.33	68.66	84.55	83.85
Z ₃	45.81	66.22	84.07	83.55
Z ₄	49.85	67.15	82.29	81.44
SE m ±	2.10	2.33	2.78	2.66
CD (P=0.05)	6.10	6.75	8.07	7.72
N×Z	NS	NS	NS	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.2: Effect of nitrogen and zinc scheduling on number of tiller plant⁻¹

Treatments	Tiller no. plant ⁻¹			
	30 DAS	60DAS	90 DAS	Harvest
Nitrogen rate				
N ₀	36.47	73.27	53.47	37.53
N ₁	48.40	90.67	65.73	56.87
N ₂	62.00	97.00	73.67	71.07
SEm ±	1.55	2.16	1.95	2.10
CD (P=0.05)	4.48	6.26	5.65	6.07
Scheduling of Zinc				
Z ₀	41.89	71.22	55.56	49.22
Z ₁	47.00	84.78	62.33	51.56
Z ₂	53.78	99.33	74.44	66.89
Z ₃	51.00	89.22	64.00	53.67
Z ₄	51.11	90.33	65.11	54.44
SE m ±	2.00	2.79	2.52	2.71
CD (P=0.05)	5.79	8.08	7.30	7.84
N×Z	NS	NS	NS	S

N₀ = 0 kg N ha⁻¹ (control)N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)Z₀ = 0 kg Zn/ha⁻¹ (control)Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.3: Effect of nitrogen and zinc scheduling on SPAD value

Treatment	30 DAS	60DAS	90 DAS
Nitrogen rate			
N ₀	29.97	28.14	27.14
N ₁	29.34	31.05	28.55
N ₂	31.71	35.20	30.25
SEm ±	1.42	0.51	0.63
CD (P=0.05)	NS	1.47	1.83
Scheduling of Zinc			
Z ₀	26.85	30.16	29.01
Z ₁	30.72	31.58	29.32
Z ₂	32.00	32.96	27.90
Z ₃	32.11	32.24	28.49
Z ₄	30.00	30.37	28.53
SE m ±	1.83	0.65	0.81
CD (P=0.05)	NS	1.89	NS
N×Z	NS	NS	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.4: Effect of nitrogen and zinc scheduling on leaf area index (LAI)

Treatments	30 DAS	60DAS	90 DAS
Nitrogen rate			
N ₀	0.49	0.97	1.77
N ₁	0.59	2.47	3.20
N ₂	0.97	3.86	4.47
SEm ±	0.03	0.08	0.08
CD (P=0.05)	0.08	0.22	0.24
Scheduling of Zinc			
Z ₀	0.51	1.95	2.70
Z ₁	0.72	2.32	3.02
Z ₂	0.68	2.51	3.36
Z ₃	0.68	2.70	3.35
Z ₄	0.84	2.68	3.31
SE m ±	0.04	0.10	0.11
CD (P=0.05)	0.10	0.28	0.31
N×Z	S	S	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.5: Effect of N and Zn scheduling on dry matter accumulation in shoots

Treatments	Dry matter accumulation in shoots (running m ⁻¹)			
	30 DAS	60DAS	90 DAS	Harvest
Nitrogen rate				
N ₀	7.64	45.21	110.41	118.81
N ₁	11.88	92.84	180.54	196.02
N ₂	16.97	119.10	215.05	235.53
SEm ±	0.35	2.14	3.24	4.66
CD (P=0.05)	1.02	6.19	9.40	13.51
Scheduling of Zinc				
Z ₀	10.48	56.67	133.92	158.35
Z ₁	11.27	86.55	161.93	172.13
Z ₂	12.63	102.67	186.48	200.78
Z ₃	13.12	91.53	183.08	199.68
Z ₄	13.31	91.16	177.92	186.33
SE m ±	0.45	2.67	4.19	6.02
CD (P=0.05)	1.31	7.99	12.14	17.44
N×Z	NS	S	S	S
N ₀ = 0 kg N ha ⁻¹ (control)				
N ₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)				
N ₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)				
Z ₀ = 0 kg Zn/ha ⁻¹ (control)				
Z ₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61				
Z ₂ = 10 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61				
Z ₃ = 5 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73				
Z ₄ = 10 kg Zn/ha at basal +0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73				

Table 4.1.6: Effect of N and Zn scheduling on dry matter accumulation in roots

Treatments	Dry matter accumulation in roots (running m ⁻¹)			
	30 DAS	60DAS	90 DAS	Harvest
Nitrogen rate				
N ₀	6.59	16.41	56.00	52.00
N ₁	8.59	29.95	70.75	69.41
N ₂	13.68	39.83	83.70	80.36
SEm ±	0.47	0.79	2.01	1.75
CD (P=0.05)	1.37	2.29	5.83	5.08
Scheduling of Zinc				
Z ₀	7.11	19.53	59.31	58.20
Z ₁	10.60	29.26	67.67	64.34
Z ₂	9.90	31.54	73.76	70.42
Z ₃	10.70	30.16	78.43	75.09
Z ₄	9.79	33.17	71.57	68.24
SE m ±	0.61	1.02	2.60	2.26
CD (P=0.05)	1.77	2.96	7.52	6.56
N×Z	S	S	NS	NS
N ₀ = 0 kg N ha ⁻¹ (control)				
N ₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)				
N ₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)				
Z ₀ = 0 kg Zn/ha ⁻¹ (control)				
Z ₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61				
Z ₂ = 10 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61				
Z ₃ = 5 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73				
Z ₄ = 10 kg Zn/ha at basal +0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73				

Table 4.1.7: Effect of nitrogen and zinc scheduling on crop growth rate (CGR)

Treatments	30 DAS	60DAS	90 DAS
Nitrogen rate			
N ₀	0.255	1.252	2.563
N ₁	0.396	2.699	4.498
N ₂	0.566	3.404	5.199
SEm ±	0.012	0.072	0.130
CD (P=0.05)	0.034	0.208	0.375
Scheduling of Zinc			
Z ₀	0.349	1.540	3.108
Z ₁	0.376	2.509	3.983
Z ₂	0.421	3.001	4.664
Z ₃	0.437	2.614	4.492
Z ₄	0.444	2.595	4.186
SE m ±	0.015	0.093	0.167
CD (P=0.05)	0.044	0.269	0.485
N×Z	NS	S	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.8: Effect of nitrogen and zinc scheduling on relative growth rate (RGR)

Treatments	30 DAS	60DAS	90 DAS
Nitrogen rate			
N ₀	0.111	0.400	0.481
N ₁	0.172	0.948	1.094
N ₂	0.246	1.158	1.144
SEm ±	0.005	0.033	0.079
CD (P=0.05)	0.015	0.095	0.229
Scheduling of Zinc			
Z ₀	0.152	0.471	0.583
Z ₁	0.163	0.877	0.929
Z ₂	0.183	1.065	1.148
Z ₃	0.190	0.888	1.039
Z ₄	0.193	0.876	0.831
SE m ±	0.007	0.042	0.102
CD (P=0.05)	0.019	0.123	0.296
N×Z	NS	S	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.2.1: Effect of nitrogen and zinc scheduling on yield attributes

Treatments	Effective Tillers (running m ⁻¹)	Panicle length (cm)	Grain panicle ⁻¹	Panicle weight (g)	Test weight (g)
Nitrogen rate					
N ₀	37.53	21.66	85.00	1.90	18.35
N ₁	56.87	23.51	101.13	2.46	20.75
N ₂	71.07	23.87	112.67	2.76	23.53
SEm ±	2.10	0.60	2.73	0.07	0.50
CD (P=0.05)	6.07	1.73	6.85	0.19	1.45
Scheduling of Zinc					
Z ₀	49.22	22.59	88.44	2.02	17.86
Z ₁	51.56	22.21	96.78	2.34	20.32
Z ₂	66.89	22.98	105.89	2.57	23.66
Z ₃	53.67	24.16	102.00	2.50	21.26
Z ₄	54.44	23.12	104.89	2.45	21.29
SEm ±	2.71	0.77	3.05	0.09	0.65
CD (P=0.05)	7.84	NS	8.85	0.25	1.87
N×Z	S	NS	S	S	S
N ₀ = 0 kg N ha ⁻¹ (control)					
N ₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)					
N ₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)					
Z ₀ = 0 kg Zn/ha ⁻¹ (control)					
Z ₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61					
Z ₂ = 10 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 45 + 0.3% ZnSo ₄ spray at G 61					
Z ₃ = 5 kg Zn/ha at basal + 0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73					
Z ₄ = 10 kg Zn/ha at basal +0.3% ZnSo ₄ spray at G 51 + 0.3% ZnSo ₄ spray at G 73					

Table 4.2.2: Effect of nitrogen and zinc scheduling on yield attributes

Treatments	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index (%)
Nitrogen rate				
N ₀	1957.52	4522.59	6473.44	30.16
N ₁	2801.96	5138.78	7854.07	34.06
N ₂	3817.71	6384.94	10202.98	37.29
SEm ±	75.26	138.29	203.95	0.68
CD (P=0.05)	218.02	400.62	590.83	1.96
Scheduling of Zinc				
Z ₀	1975.56	4567.07	6453.75	29.92
Z ₁	2851.93	5451.78	8248.15	33.56
Z ₂	3442.59	5567.59	9010.17	36.83
Z ₃	2985.84	5658.50	8633.22	34.13
Z ₄	3039.40	5498.91	8538.86	34.72
SEm ±	97.16	178.54	263.30	0.87
CD (P=0.05)	281.47	517.20	762.76	2.53
N×Z	S	S	S	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.5.1: Effect of nitrogen and zinc scheduling on protein content and protein yield

Treatments	Protein content (%)	Protein yield (kg ha ⁻¹)
Nitrogen rate		
N ₀	5.348	106.404
N ₁	6.888	195.947
N ₂	9.483	376.055
SEm ±	0.239	10.961
CD (P=0.05)	0.693	31.752
Scheduling of Zinc		
Z ₀	5.574	113.067
Z ₁	7.063	218.063
Z ₂	8.222	299.783
Z ₂	7.069	224.750
Z ₄	8.271	275.013
SEm ±	0.309	14.150
CD (P=0.05)	0.895	40.992
N×Z	S	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.6.1: Effect of nitrogen and zinc scheduling on yield economics

Treatments	Cost of cultivation ₹ ha⁻¹	Gross returns ₹ ha⁻¹	Net returns ₹ ha⁻¹	B:C ratio
Nitrogen rate				
N ₀	28727.95	44996.10	16268.15	0.57
N ₁	30136.65	59734.91	29598.26	0.98
N ₂	30606.18	79231.12	48624.94	1.58
SEm ±	-	1453.25	1453.25	0.05
CD (P=0.05)	-	4209.90	4209.90	0.14
Scheduling of Zinc				
Z ₀	29175.59	45420.64	16245.05	0.55
Z ₁	29795.59	61574.92	31779.32	1.06
Z ₂	30195.59	70781.12	40585.52	1.33
Z ₃	29775.59	64293.70	34518.10	1.15
Z ₄	30175.59	64533.18	34357.59	1.13
SEm ±	-	1876.14	1876.14	0.06
CD (P=0.05)	-	5434.96	5434.96	0.18
N×Z		S	S	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.1: Effect of nitrogen and zinc scheduling on N, P, K, and Zn content in grain and straw.

Treatments	N content (%)		P content (%)		K content (%)		Zn content (%)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Nitrogen rate								
N ₀	0.856	0.350	0.206	0.078	0.257	1.150	21.623	55.895
N ₁	1.102	0.491	0.241	0.082	0.294	1.201	30.475	60.182
N ₂	1.517	0.575	0.256	0.083	0.276	1.250	38.922	71.449
SEm ±	0.038	0.021	0.009	0.003	0.009	0.029	1.218	2.307
CD (P=0.05)	0.111	0.060	0.026	NS	0.025	NS	3.530	6.683
Scheduling of Zinc								
Z ₀	0.892	0.392	0.197	0.077	0.236	1.169	20.577	38.019
Z ₁	1.130	0.483	0.252	0.084	0.293	1.186	27.099	56.062
Z ₂	1.316	0.506	0.237	0.082	0.295	1.272	30.547	67.683
Z ₃	1.131	0.474	0.255	0.082	0.266	1.193	34.187	72.113
Z ₄	1.323	0.506	0.231	0.078	0.288	1.183	39.292	78.667
SEm ±	0.049	0.027	0.012	0.004	0.011	0.038	1.573	2.978
CD (P=0.05)	0.143	0.077	0.034	NS	0.032	NS	4.557	8.628
N×Z	S	NS	S	NS	S	NS	S	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.2: Effect of nitrogen and zinc scheduling on N, P, K, and Zn uptake in grain and straw.

Treatments	N uptake (kg ha ⁻¹)		P uptake (kg ha ⁻¹)		K uptake (kg ha ⁻¹)		Zn uptake (kg ha ⁻¹)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Nitrogen rate								
N ₀	17.025	16.001	4.133	3.523	5.140	52.015	0.042	0.254
N ₁	31.351	25.238	6.781	4.230	8.246	61.650	0.087	0.314
N ₂	60.169	37.345	9.659	5.261	10.537	80.072	0.155	0.466
SEm ±	1.754	1.336	0.364	0.202	0.292	2.020	0.004	0.016
CD (P=0.05)	5.080	3.869	1.053	0.585	0.847	5.850	0.013	0.047
Scheduling of Zinc	18.091	17.908	4.151	3.533	4.826	53.236	0.041	0.176
Z ₀	34.890	27.352	7.257	4.646	8.266	65.274	0.082	0.316
Z ₁	47.965	29.249	8.189	4.586	10.098	70.985	0.113	0.383
Z ₂	35.960	27.842	7.639	4.596	7.965	68.158	0.108	0.412
Z ₃	44.002	28.624	7.051	4.330	8.717	65.243	0.130	0.438
Z ₄	2.264	1.724	0.469	0.261	0.378	2.607	0.006	0.021
SEm ±	6.559	4.995	1.360	0.755	1.094	7.553	0.016	0.061
CD (P=0.05)	S	S	NS	NS	NS	S	S	NS
N×Z	S	NS	S	NS	S	NS	S	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.3: Effect of nitrogen and zinc scheduling on total N, P, K, and Zn uptake.

Treatments	N uptake (kg ha⁻¹)	P uptake (kg ha⁻¹)	K uptake (kg ha⁻¹)	Zn uptake (kg ha⁻¹)
Nitrogen rate				
N ₀	33.026	7.656	57.155	0.296
N ₁	56.590	11.011	69.896	0.401
N ₂	97.514	14.920	90.608	0.622
SEm ±	2.327	0.448	2.127	0.016
CD (P=0.05)	6.742	1.299	6.161	0.047
Scheduling of Zinc				
Z ₀	35.998	7.684	58.062	0.217
Z ₁	62.242	11.903	73.540	0.398
Z ₂	77.215	12.775	81.083	0.495
Z ₃	63.802	12.235	76.122	0.520
Z ₄	72.626	11.382	73.960	0.569
SEm ±	3.005	0.579	2.746	0.021
CD (P=0.05)	8.704	1.677	7.954	0.060
N×Z	S	NS	S	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.4.1: Effect of nitrogen and zinc scheduling on nitrogen use efficiency

Treatments	Partial factor productivity (kg grain kg ⁻¹ N)	Agronomic efficiency (kg grain increase kg ⁻¹ N)	Recovery efficiency (%)	N harvest index (%)	Physiological efficiency (kg grain kg ⁻¹ N uptake)
Nitrogen rate					
N ₀	0.000	0.000	0.000	51.287	24.073
N ₁	23.350	9.873	25.922	54.493	39.700
N ₂	23.861	13.753	45.019	60.537	32.857
SE m±	0.555	0.584	1.746	2.021	7.507
C.D. (P=0.05)	1.608	1.692	5.058	5.854	NS
Scheduling of Zinc					
Z ₀	10.393	2.533	7.613	49.404	24.819
Z ₁	15.507	7.645	23.763	53.918	29.785
Z ₂	19.189	11.327	32.692	61.092	43.201
Z ₃	16.610	8.747	24.446	54.602	44.797
Z ₄	16.987	9.125	29.720	58.179	18.448
SE m±	0.717	0.754	2.254	2.609	9.692
C.D. (P=0.05)	2.076	2.184	6.53	7.557	NS
N×Z	S	S	S	NS	S

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.4.2: Effect of nitrogen and zinc scheduling on zinc use efficiency

Treatments	Partial factor productivity (kg grain kg ⁻¹ Zn)	Agronomic efficiency (kg grain kg ⁻¹ Zn)	Recovery efficiency (%)	Zinc harvest index (%)	Physiological efficiency (kg grain kg ⁻¹ Zn uptake)
Nitrogen rate					
N ₀	209.381	42.526	1.836	15.261	2310.995
N ₁	304.325	137.470	2.944	21.817	5171.322
N ₂	424.930	258.075	5.688	24.325	4846.791
SE m±	8.820	8.880	0.197	1.131	556.996
C.D. (P=0.05)	25.551	25.724	0.570	3.275	1613.554
Scheduling of Zinc					
Z ₀	0.000	0.000	0.000	19.683	3975.644
Z ₁	476.114	206.129	4.204	19.887	4723.253
Z ₂	313.247	166.094	3.173	21.663	5393.216
Z ₃	498.470	228.485	6.230	19.770	3501.014
Z ₄	276.560	129.407	3.840	21.335	2955.387
SE m±	11.387	11.464	0.254	1.460	719.079
C.D. (P=0.05)	32.986	33.209	0.735	NS	NS
N×Z	S	S	S	NS	NS

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.1(a): Integrated effect of nitrogen and zinc scheduling on number of tillers at harvesting.

Treatments	Number of tillers (running m ⁻¹)					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	35.00	38.00	41.67	36.33	36.67	37.53
N ₁	48.00	55.67	62.33	58.33	60.00	56.87
N ₂	64.67	61.00	96.67	66.33	66.67	71.07
Mean	49.22	51.56	66.89	53.67	54.44	
	SEm±		4.69	C.D(P=0.05)		13.58

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.5 (c): Integrated effect of nitrogen and zinc scheduling on shoot dry weight at maturity.

Treatments	Shoot dry weight (g running m ⁻¹)					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	101.39	108.20	138.23	126.52	119.73	118.81
N ₁	171.93	193.75	225.52	218.10	170.80	196.02
N ₂	201.74	214.43	238.58	254.43	268.45	235.53
Mean	158.35	172.13	200.78	199.68	186.33	
	SEm±		10.43	C.D(P=0.05)		30.21

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.2.2 (c): Integrated effect of nitrogen and zinc scheduling on biological yield.

Treatments	Biological yield (kg/ha)					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	5998.60	6665.80	6757.78	6368.96	6576.05	6473.44
N ₁	6391.40	7232.24	8744.02	8858.39	8044.32	7854.07
N ₂	6971.24	10846.41	11528.70	10672.32	10996.22	10202.98
Mean	6453.75	8248.15	9010.17	8633.22	8538.86	
	SEm±		456.06	C.D(P=0.05)		1321.14

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.3 (c): Integrated effect of nitrogen and zinc scheduling on total Zn uptake

Treatments	Total Zn uptake (kg/ha)					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	0.15	0.26	0.34	0.35	0.39	0.30
N ₁	0.23	0.32	0.47	0.48	0.51	0.40
N ₂	0.28	0.62	0.68	0.73	0.81	0.62
Mean	1 0.22	0.40	0.50	0.52	0.57	
	SEm±		0.04	C.D(P=0.05)		0.10

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.4 (a): Integrated effect of nitrogen and zinc scheduling on LAI at 30 DAS.

Treatments	LAI					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	0.40	0.52	0.53	0.42	0.60	0.49
N ₁	0.42	0.78	0.57	0.52	0.66	0.59
N ₂	0.69	0.87	0.94	1.09	1.27	0.97
Mean	0.51	0.72	0.68	0.68	0.84	
	SEm±		0.06	C.D(P=0.05)		0.18

Table 4.1.4 (b): Integrated effect of nitrogen and zinc scheduling on LAI at 60 DAS.

Treatments	LAI					
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	0.75	0.91	1.10	1.07	1.00	0.97
N ₁	1.48	2.33	2.74	2.89	2.90	2.47
N ₂	3.61	3.74	3.69	4.14	4.13	3.86
Mean	1.95	2.32	2.51	2.70	2.68	
SEm±	0.17				C.D(P=0.05)	0.49

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.5 (a): Integrated effect of nitrogen and zinc scheduling on shoot dry weight at 60 DAS.

Treatment s	Shoot dry weight (running m ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	30.71	43.52	50.35	50.15	51.30	45.21
N ₁	58.83	103.83	101.88	101.91	97.76	92.84
N ₂	80.46	112.29	155.77	122.53	124.43	119.10
Mean	56.67	86.55	102.67	91.53	91.16	
SEm±	4.78				C.D(P=0.05)	13.83

Table 4.1.5 (b): Integrated effect of nitrogen and zinc scheduling on shoot dry weight at 90 DAS.

Treatments	Shoot dry weight (running m ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	95.24	99.37	125.47	119.47	112.50	110.41
N ₁	158.24	176.70	200.72	210.22	156.80	180.54
N ₂	148.26	209.72	233.25	219.56	264.45	215.05
Mean	133.22	161.93	186.48	183.08	177.92	
SEm±	7.26				C.D(P=0.05)	21.02

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.6 (a): Integrated effect of nitrogen and zinc scheduling on root dry weight at 30

DAS.

		Root dry weight (running m ⁻¹)				
Treatment s	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	4.73	7.47	7.25	6.11	7.40	6.59
N ₁	6.51	7.73	10.28	11.38	7.06	8.59
N ₂	10.10	16.60	12.18	14.61	14.92	13.68
Mean	7.11	10.60	9.90	10.70	9.79	
SEm±	1.06				C.D(P=0.05)	3.06

Table 4.1.6 (b): Integrated effect of nitrogen and zinc scheduling on root dry weight at 60 DAS.

		Root dry weight (running m ⁻¹)				
Treatment s	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	9.16	13.96	14.49	20.76	23.68	16.41
N ₁	23.69	31.43	35.44	31.85	27.33	29.95
N ₂	25.72	42.38	44.69	37.87	48.50	39.83
Mean	19.53	29.26	31.54	30.16	33.17	
SEm±	1.77				C.D(P=0.05)	5.13

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.7 (a): Integrated effect of nitrogen and zinc scheduling on crop growth rate (CGR) at 60 DAS.

CGR at 60 DAS (g running m ⁻¹ d ⁻¹)						
Treatment s	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	0.80	1.27	1.38	1.39	1.42	1.25
N ₁	1.62	3.06	2.99	2.95	2.87	2.70
N ₂	2.20	3.20	4.63	3.49	3.49	3.40
Mean	1.54	2.51	3.00	2.61	2.60	
SEm±	0.16				C.D(P=0.05)	0.47

Table 4.1.7 (b): Integrated effect of nitrogen and zinc scheduling crop growth rate (CGR) at 90 DAS.

CGR at 90 DAS (g running m ⁻¹ d ⁻¹)						
Treatment s	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	Mean
N ₀	2.19	2.29	3.04	2.88	2.42	2.56
N ₁	3.92	4.41	5.25	5.43	3.48	4.50
N ₂	3.22	5.25	5.71	5.16	6.66	5.20
Mean	3.11	3.98	4.66	4.49	4.19	
SEm±	0.29				C.D(P=0.05)	0.84

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.1.8 (a): Integrated effect of nitrogen and zinc scheduling on relative growth rate RGR at 60 DAS.

		RGR at 60 DAS (g g ⁻¹ running m ⁻¹ d ⁻¹)				
Treatment		Z ₁	Z ₂	Z ₃	Z ₄	Mean
s	Z ₀					
N ₀	0.22	0.45	0.43	0.45	0.45	0.40
N ₁	0.51	1.10	1.07	1.03	1.03	0.95
N ₂	0.68	1.09	1.69	1.18	1.15	1.16
Mean	0.47	0.88	1.07	0.89	0.88	
SEm±	0.07				C.D(P=0.05)	0.21

Table 4.1.8 (b): Integrated effect of nitrogen and zinc scheduling on relative growth rate RGR at 90 DAS.

		RGR at 90 DAS (g g ⁻¹ running m ⁻¹ d ⁻¹)				
Treatment		Z ₁	Z ₂	Z ₃	Z ₄	Mean
s	Z ₀					
N ₀	0.39	0.42	0.67	0.63	0.30	0.48
N ₁	0.94	1.08	1.46	1.47	0.53	1.09
N ₂	0.42	1.29	1.31	1.02	1.67	1.14
Mean	0.58	0.93	1.15	1.04	0.83	
SEm±	0.18				C.D(P=0.05)	0.51

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

$Z_3 = 5 \text{ kg Zn/ha at basal} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 51} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 73}$

$Z_4 = 10 \text{ kg Zn/ha at basal} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 51} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 73}$

Table 4.2.1 (a): Integrated effect of nitrogen and zinc scheduling on number of Effective

tillers at harvesting.

Treatments	number of tillers (running m ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	35.00	38.00	41.67	36.33	36.67	37.53
N ₁	48.00	55.67	62.33	58.33	60.00	56.87
N ₂	64.67	61.00	96.67	66.33	66.67	71.07
Mean	49.22	51.56	66.89	53.67	54.44	
SEm±	4.69				C.D(P=0.05)	13.58

Table 4.2.1 (b): Integrated effect of nitrogen levels and zinc scheduling number of

grains/panicle.

Treatment s	Grains / panicle					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	77.67	87.67	97.00	74.00	88.67	85.00
N ₁	93.00	97.67	99.00	107.67	108.33	101.13
N ₂	94.67	105.00	121.67	124.33	117.67	112.67
Mean	88.44	96.78	105.89	102.00	104.89	
SEm±	5.29				C.D(P=0.05)	15.33

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.2.1 (c): Integrated effect of nitrogen and zinc scheduling on panicle weight.

Treatments	Panicle weight(g)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	1.56	2.06	2.26	1.74	1.90	1.90
N ₁	1.75	2.33	2.75	2.64	2.84	2.46
N ₂	2.74	2.63	2.71	3.13	2.61	2.76
Mean	2.02	2.34	2.57	2.50	2.45	
SEm±	0.15				C.D(P=0.05)	0.43

Table 4.2.1 (d): Integrated effect of nitrogen and zinc scheduling on test weight.

Treatment s	Test weight (g)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	12.93	18.93	19.67	20.73	19.47	18.35
N ₁	18.27	20.40	22.43	21.07	21.57	20.75
N ₂	22.37	21.63	28.87	21.97	22.83	23.53
Mean	17.86	20.32	23.66	21.26	21.29	
SEm±	1.12				C.D(P=0.05)	3.24

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.2.2 (a): Integrated effect of nitrogen and zinc scheduling on grain yield.

Treatment s	Grain yield (kg/ha)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀			2266.8			
	1617.21	1987.58	8	2007.84	1908.08	1957.52
N ₁			3448.8			
	2038.89	2624.84	0	3067.76	2829.50	2801.96
N ₂			4612.0			
	2270.59	3943.36	8	3881.91	4380.61	3817.71
Mean	1		3442.5		3039.40	
	1975.56	2851.93	9	2985.84		
SEm±	168.29				C.D(P=0.05)	487.52

Table 4.2.2 (b): Integrated effect of nitrogen and zinc scheduling on straw yield.

Treatment s	Straw yield (kg/ha)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀			4490.9			
	4381.38	4678.21	2	4394.45	4667.97	4522.59
N ₁			5295.2			
	4619.71	4774.07	2	5790.63	5214.82	5138.78
N ₂			6916.6			
	4700.66	6903.05	3	6790.41	6613.94	6384.94
Mean			5567.5		5498.91	
	4567.07	5451.78	9	5658.50		
SEm±	309.23				C.D(P=0.05)	895.82

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSO₄ spray at G 45 + 0.3% ZnSO₄ spray at G 61

$Z_2 = 10 \text{ kg Zn/ha at basal} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 45} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 61}$

$Z_3 = 5 \text{ kg Zn/ha at basal} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 51} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 73}$

$Z_4 = 10 \text{ kg Zn/ha at basal} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 51} + 0.3\% \text{ ZnSo}_4 \text{ spray at G 73}$

Table 4.3.1 (a): Integrated effect of nitrogen and zinc scheduling on N content in grain

Treatments	N content in grain (%)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.70	0.74	0.97	0.88	1.00	0.86
N ₁	0.97	1.13	1.31	0.94	1.16	1.10
N ₂	1.01	1.53	1.67	1.58	1.81	1.52
Mean	1				1.32	
SEm±	0.89	1.13	1.32	1.13		
	0.09				C.D(P=0.05)	0.25

Table 4.3.1 (b): Integrated effect of nitrogen and zinc scheduling on P content in grain

Treatments	P content in grain (%)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.07	0.24	0.25	0.25	0.23	0.21
N ₁	0.24	0.26	0.21	0.26	0.23	0.24
N ₂	0.28	0.26	0.25	0.26	0.23	0.26
Mean	0.20	0.25	0.24	0.25	0.23	
SEm±	0.02					
					C.D(P=0.05)	0.06

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.1 (c): Integrated effect of nitrogen and zinc scheduling on K content in grain

Treatments	K content in grain (%)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.15	0.30	0.30	0.25	0.29	0.26
N ₁	0.29	0.30	0.30	0.29	0.29	0.29
N ₂	0.27	0.28	0.29	0.26	0.28	0.28
Mean	1				0.29	
SEm±	0.24	0.29	0.30	0.27		
	0.02				C.D(P=0.05)	0.06

Table 4.3.1 (d): Integrated effect of nitrogen and zinc scheduling on Zn content in grain

Treatments	Zn content in grain (mg)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	17.40	20.85	20.40	24.03	25.43	21.62
N ₁	23.04	24.09	31.59	32.77	40.89	30.48
N ₂	21.29	36.36	39.65	45.76	51.56	38.92
Mean	1				39.29	
SEm±	20.58	27.10	30.55	34.19		
	2.72				C.D(P=0.05)	7.89

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.2 (a): Integrated effect of nitrogen and zinc scheduling on N uptake by grain

Treatment s	N uptake by grain (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	11.42	14.60	21.96	18.07	19.08	17.02
N ₁	20.01	29.67	45.44	28.62	33.02	31.35
N ₂	22.85	60.40	76.50	61.19	79.91	60.17
Mean	1				44.00	
	18.09	34.89	47.97	35.96		
SEm±	3.92				C.D(P=0.05)	11.36

Table 4.3.2 (b): Integrated effect of nitrogen and zinc scheduling on N uptake by straw

Treatment s	N uptake by straw (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	14.07	16.80	17.12	15.40	16.62	16.00
N ₁	20.47	24.94	26.01	27.97	26.80	25.24
N ₂	19.19	40.32	44.61	40.16	42.45	37.34
Mean	1				28.62	
	17.91	27.35	29.25	27.84		
SEm±	2.99				C.D(P=0.05)	8.65

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSO₄ spray at G 51 + 0.3% ZnSO₄ spray at G 73

Table 4.3.2 (c): Integrated effect of nitrogen and zinc scheduling on K uptake by straw

Treatment s	K uptake by straw (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	48.75	51.93	54.30	50.07	55.03	52.02
N ₁	55.38	53.46	71.84	68.24	59.34	61.65
N ₂	55.58	90.43	86.82	86.16	81.37	80.07
Mean	1				65.24	
	53.24	65.27	70.98	68.16		
SEm±	4.52				C.D(P=0.05)	13.08

Table 4.3.2 (d): Integrated effect of nitrogen and zinc scheduling on Zn uptake by grain

Treatment s	Zn uptake by grain (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.03	0.04	0.05	0.05	0.05	0.04
N ₁	0.05	0.06	0.11	0.10	0.12	0.09
N ₂	0.05	0.14	0.18	0.18	0.23	0.16
Mean	1				0.13	
	0.04	0.08	0.11	0.11		
SEm±	0.01				C.D(P=0.05)	0.03

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.3.3 (a): Integrated effect of nitrogen and zinc scheduling on total N uptake

Treatment s	Total N uptake (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	25.48	31.40	39.08	33.47	35.70	33.03
N ₁	40.47	54.61	71.45	56.59	59.82	56.59
N ₂	42.04	100.71	121.11	101.35	122.35	97.51
Mean	1				72.63	
SEm±	36.00	62.74	77.21	63.80	C.D(P=0.05)	15.08
	5.20					

Table 4.3.3 (b): Integrated effect of nitrogen and zinc scheduling on total K uptake

Treatment s	Total K uptake (kg ha ⁻¹)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	51.13	57.90	61.18	55.04	60.53	57.16
N ₁	61.31	61.33	82.05	77.20	67.59	69.90
N ₂	61.74	101.39	100.03	96.12	93.76	90.61
Mean	1				73.96	
SEm±	58.06	73.54	81.08	76.12	C.D(P=0.05)	13.78
	4.76					

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂= 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃= 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄= 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.5.1 (a): Integrated effect of nitrogen and zinc scheduling on protein content in grain

Treatment s	Protein content in grain (%)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	4.35	4.60	6.06	5.50	6.23	5.35
N ₁	6.08	7.04	8.19	5.85	7.27	6.89
N ₂	6.29	9.54	10.42	9.85	11.31	9.48
Mean	1				8.27	
	5.57	7.06	8.22	7.07		
SEm±	0.54				C.D(P=0.05)	1.55

Table 4.5.1 (b): Integrated effect of nitrogen and zinc scheduling on protein yield

Treatment s	Protein yield (kg/ha)					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	71.37	91.28	137.22	112.91	119.24	106.40
N ₁	1					
	125.05	185.43	284.00	178.88	206.38	195.95
N ₂	142.79	377.48	478.13	382.46	499.42	376.06
Mean	1				275.01	
	113.07	218.06	299.78	224.75		
SEm±	24.51				C.D(P=0.05)	71.00

N₀ = 0 kg N ha⁻¹ (control)

N₁ = 120 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

$Z_0 = 0 \text{ kg Zn/ha}^{-1}$ (control)

$Z_1 = 5 \text{ kg Zn/ha}$ at basal+ 0.3% ZnSO_4 spray at G 45 + 0.3% ZnSO_4 spray at G 61

$Z_2 = 10 \text{ kg Zn/ha}$ at basal + 0.3% ZnSO_4 spray at G 45 + 0.3% ZnSO_4 spray at G 61

$Z_3 = 5 \text{ kg Zn/ha}$ at basal + 0.3% ZnSO_4 spray at G 51 + 0.3% ZnSO_4 spray at G 73

$Z_4 = 10 \text{ kg Zn/ha}$ at basal +0.3% ZnSO_4 spray at G 51 + 0.3% ZnSO_4 spray at G 73

Table 4.4.1 (a): Integrated effect of nitrogen and zinc scheduling on partial factor productivity of N

Treatment s	Partial factor productivity of N					Mean
	Z_0	Z_1	Z_2	Z_3	Z_4	
N_0	0.00	0.00	0.00	0.00	0.00	0.00
N_1	16.99	21.87	28.74	25.57	23.58	23.35
N_2	14.19	24.65	28.83	24.26	27.38	23.86
Mean	1				16.99	
	10.39	15.51	19.19	16.61		
SEm±	1.24				C.D(P=0.05)	3.60

Table 4.4.1 (b): Integrated effect of nitrogen and zinc scheduling on agronomic efficiency of N

Treatment s	Agronomic efficiency of N					Mean
	Z_0	Z_1	Z_2	Z_3	Z_4	
N_0	0.00	0.00	0.00	0.00	0.00	0.00
N_1	3.51	8.40	15.26	12.09	10.10	9.87
N_2	4.08	14.54	18.72	14.15	17.27	13.75
Mean	1				9.12	
	2.53	7.65	11.33	8.75		
SEm±	1.31				C.D(P=0.05)	3.78

$N_0 = 0 \text{ kg N ha}^{-1}$ (control)

$N_1 = 120 \text{ kg N/ha}$ (50% at sowing + 25% at G 21 + 25% at G 32)

N₂ = 160 kg N/ha (50% at sowing + 25% at G 21 + 25% at G 32)

Z₀ = 0 kg Zn/ha⁻¹ (control)

Z₁ = 5 kg Zn/ha at basal+ 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₂ = 10 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 45 + 0.3% ZnSo₄ spray at G 61

Z₃ = 5 kg Zn/ha at basal + 0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Z₄ = 10 kg Zn/ha at basal +0.3% ZnSo₄ spray at G 51 + 0.3% ZnSo₄ spray at G 73

Table 4.4.1 (c): Integrated effect of nitrogen and zinc scheduling on recovery efficiency

of N

Treatment s	Recovery efficiency of N					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.00	0.00	0.00	0.00	0.00	0.00
N ₁	12.49	24.27	38.31	25.92	28.62	25.92
N ₂	10.35	47.02	59.77	47.42	60.54	45.02
Mean	1				29.72	
	7.61	23.76	32.69	24.45		
SEm±	3.90				C.D(P=0.05)	11.31

Table 4.4.2 (a): Integrated effect of nitrogen and zinc scheduling on partial factor

productivity of Zn

Treatment s	Partial factor productivity of Zn					Mean
	Z ₀	Z ₁	Z ₂	Z ₃	Z ₄	
N ₀	0.00	331.82	206.27	335.20	173.62	209.38
N ₁	0.00	438.20	313.81	512.15	257.46	304.32
N ₂	0.00	658.32	419.66	648.06	398.60	424.93
Mean	1				276.56	
	0.00	476.11	313.25	498.47		
SEm±	19.72				C.D(P=0.05)	57.13

N₀ = 0 kg N ha⁻¹ (control)

$N_1 = 120 \text{ kg N/ha}$ (50% at sowing + 25% at G 21 + 25% at G 32)

$N_2 = 160 \text{ kg N/ha}$ (50% at sowing + 25% at G 21 + 25% at G 32)

$Z_0 = 0 \text{ kg Zn/ha}^{-1}$ (control)

$Z_1 = 5 \text{ kg Zn/ha}$ at basal+ 0.3% ZnSo_4 spray at G 45 + 0.3% ZnSo_4 spray at G 61

$Z_2 = 10 \text{ kg Zn/ha}$ at basal + 0.3% ZnSo_4 spray at G 45 + 0.3% ZnSo_4 spray at G 61

$Z_3 = 5 \text{ kg Zn/ha}$ at basal + 0.3% ZnSo_4 spray at G 51 + 0.3% ZnSo_4 spray at G 73

$Z_4 = 10 \text{ kg Zn/ha}$ at basal +0.3% ZnSo_4 spray at G 51 + 0.3% ZnSo_4 spray at G 73

Table 4.4.2 (b): Integrated effect of nitrogen and zinc scheduling on agronomic efficiency of Zn

Treatment s	Agronomic efficiency of Zn					Mean
	Z_0	Z_1	Z_2	Z_3	Z_4	
N_0	0.00	61.83	59.11	65.21	26.47	42.53
N_1	0.00	168.22	166.66	242.16	110.31	137.47
N_2	0.00	388.34	272.51	378.08	251.45	258.07
Mean	1				129.41	
	0.00	206.13	166.09	228.49		
SEm $\pm$	19.86				C.D(P=0.05)	57.52

Table 4.4.2 (c): Integrated effect of nitrogen and zinc scheduling on recovery efficiency of Zn

Treatment s	Recovery efficiency of Zn					Mean
	Z_0	Z_1	Z_2	Z_3	Z_4	
N_0	0.00	1.86	1.72	3.34	2.26	1.84
N_1	0.00	2.83	2.98	5.64	3.26	2.94
N_2	0.00	7.91	4.82	9.71	6.00	5.69
Mean	1				3.84	
	0.00	4.20	3.17	6.23		
SEm $\pm$	0.44				C.D(P=0.05)	1.27

$N_0 = 0 \text{ kg N ha}^{-1}$ (control)

$N_1 = 120 \text{ kg N/ha}$ (50% at sowing + 25% at G 21 + 25% at G 32)

$N_2 = 160 \text{ kg N/ha}$ (50% at sowing + 25% at G 21 + 25% at G 32)

$Z_0 = 0 \text{ kg Zn/ha}^{-1}$ (control)

$Z_1 = 5 \text{ kg Zn/ha}$ at basal+ 0.3% ZnSo_4 spray at G 45 + 0.3% ZnSo_4 spray at G 61

$Z_2 = 10 \text{ kg Zn/ha}$ at basal + 0.3% ZnSo_4 spray at G 45 + 0.3% ZnSo_4 spray at G 61

$Z_3 = 5 \text{ kg Zn/ha}$ at basal + 0.3% ZnSo_4 spray at G 51 + 0.3% ZnSo_4 spray at G 73

$Z_4 = 10 \text{ kg Zn/ha}$ at basal +0.3% ZnSo_4 spray at G 51 + 0.3% ZnSo_4 spray at G 73

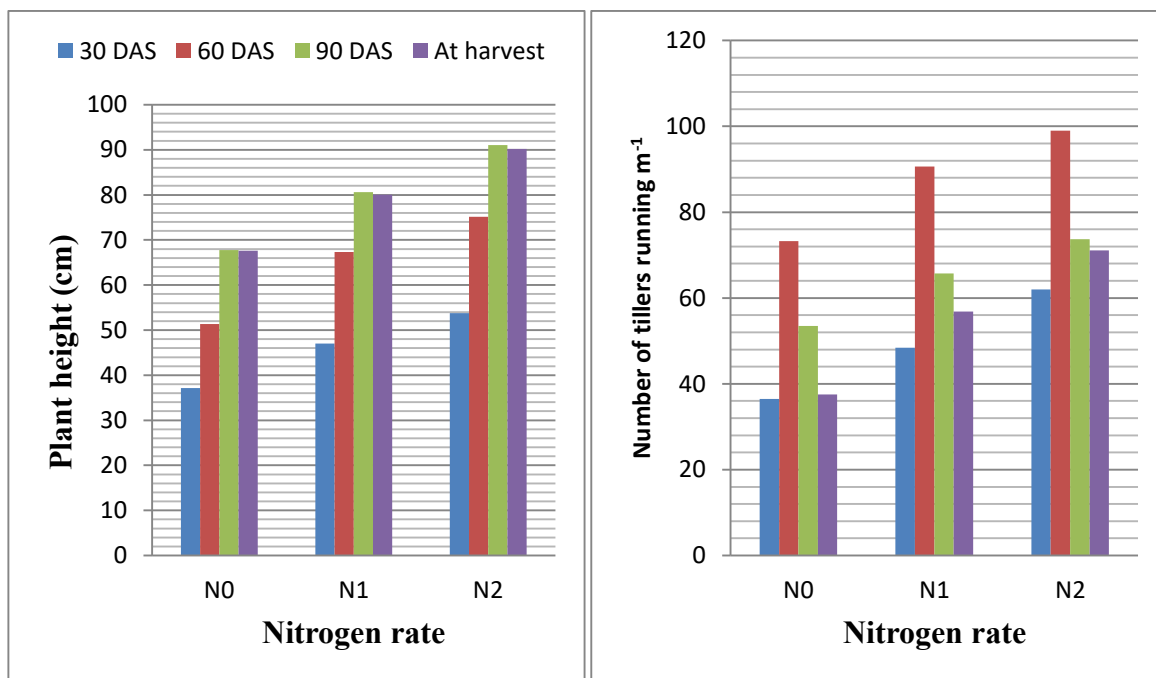


Fig 4.1(a): Effect of nitrogen rate on growth attributes

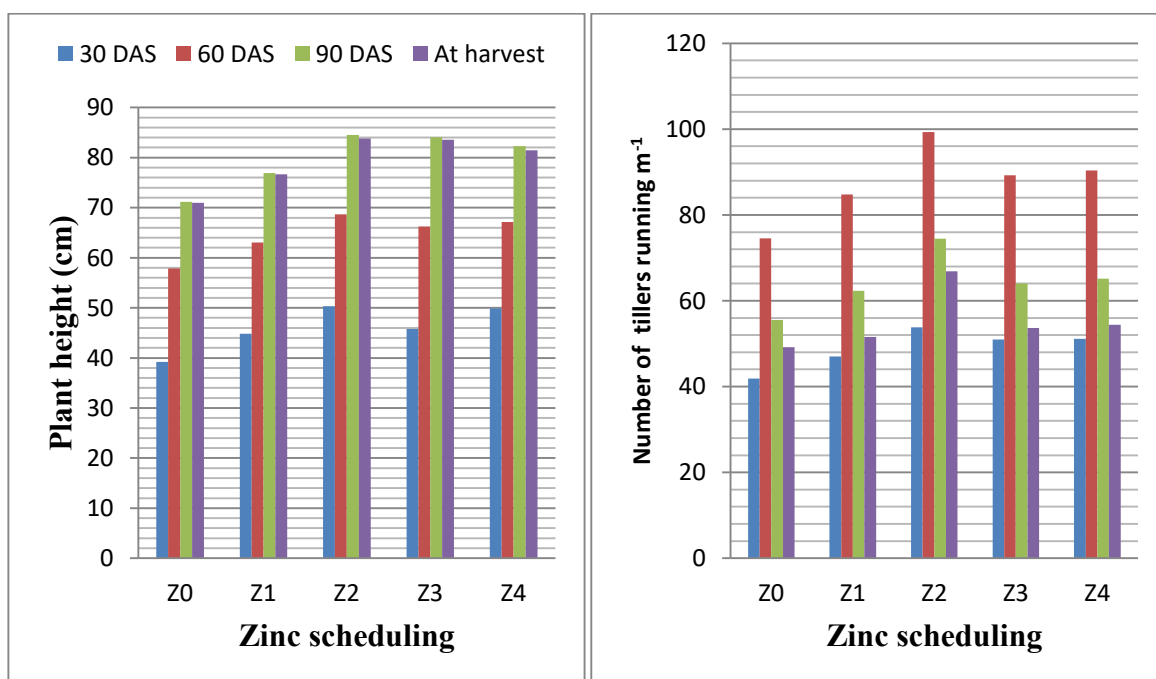


Fig 4.1(b): Effect of zinc scheduling on growth attributes

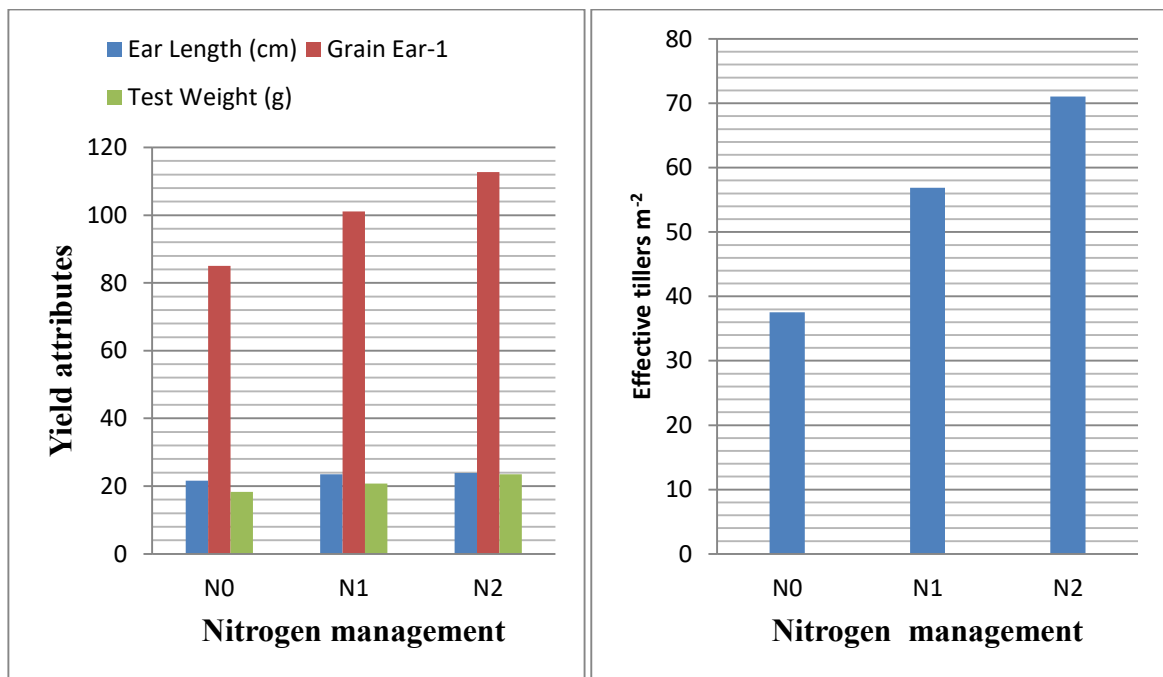


Fig 4.2(a): Effect of nitrogen rate on yield attributes

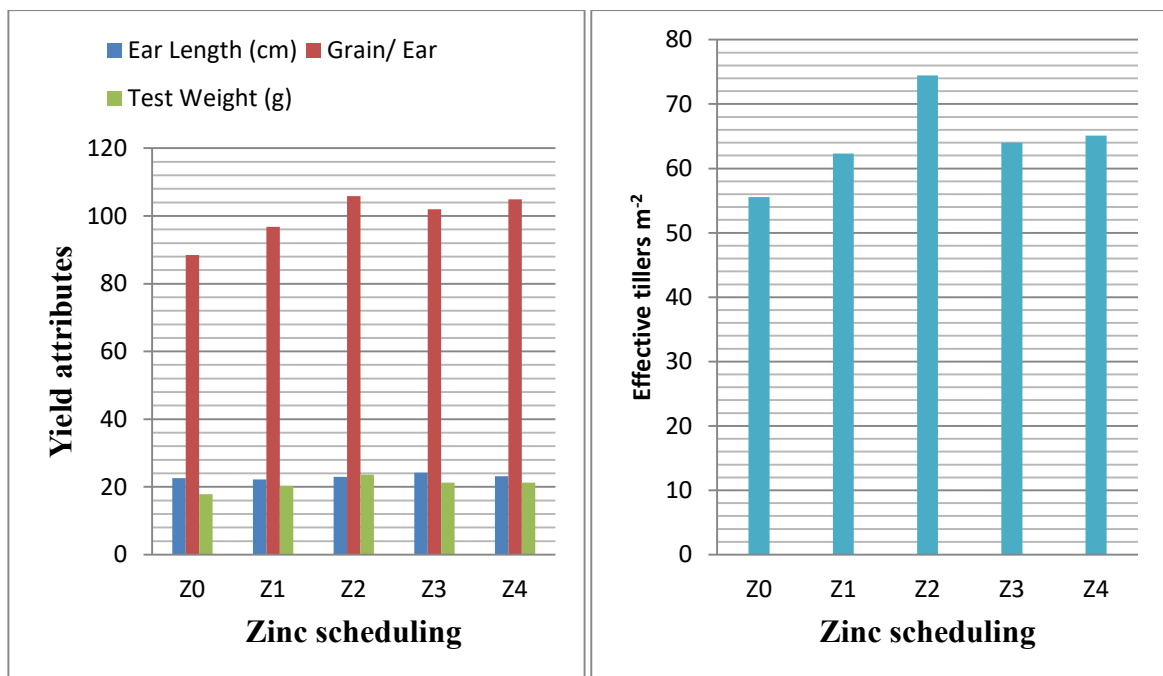


Fig 4.2(b): Effect of zinc scheduling on yield attributes

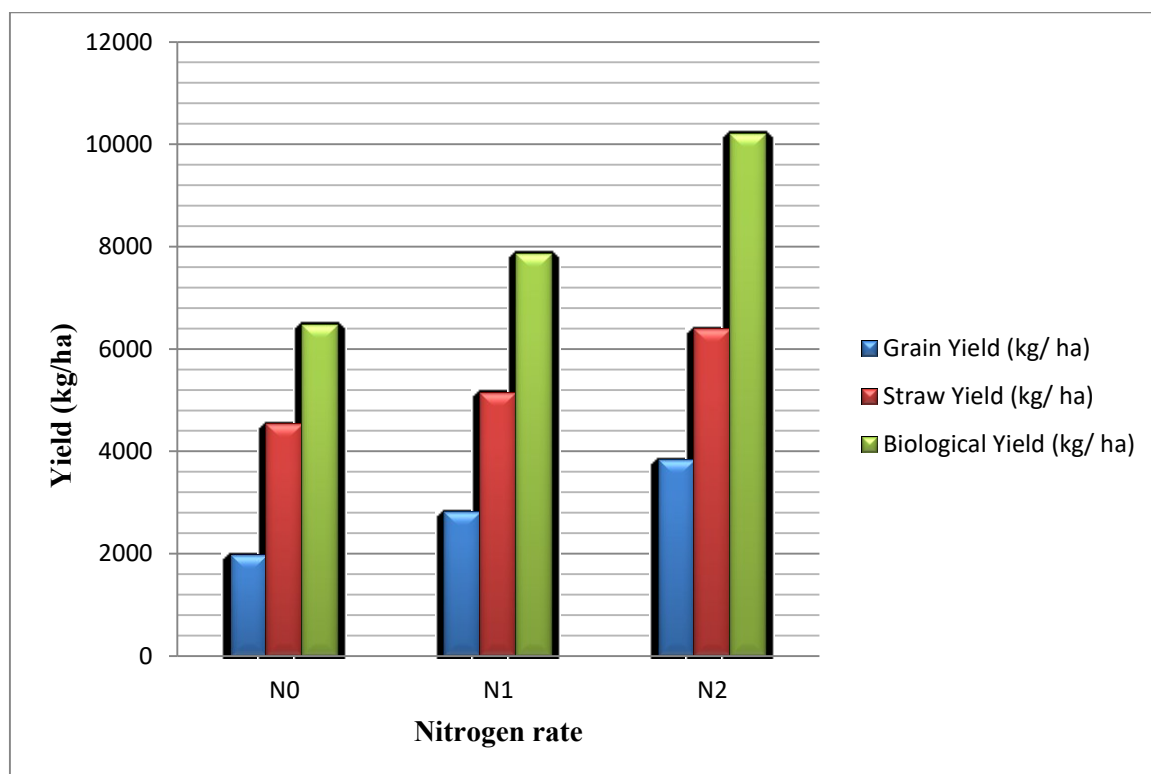


Fig 4.3(a): Effect of nitrogen rate on yield

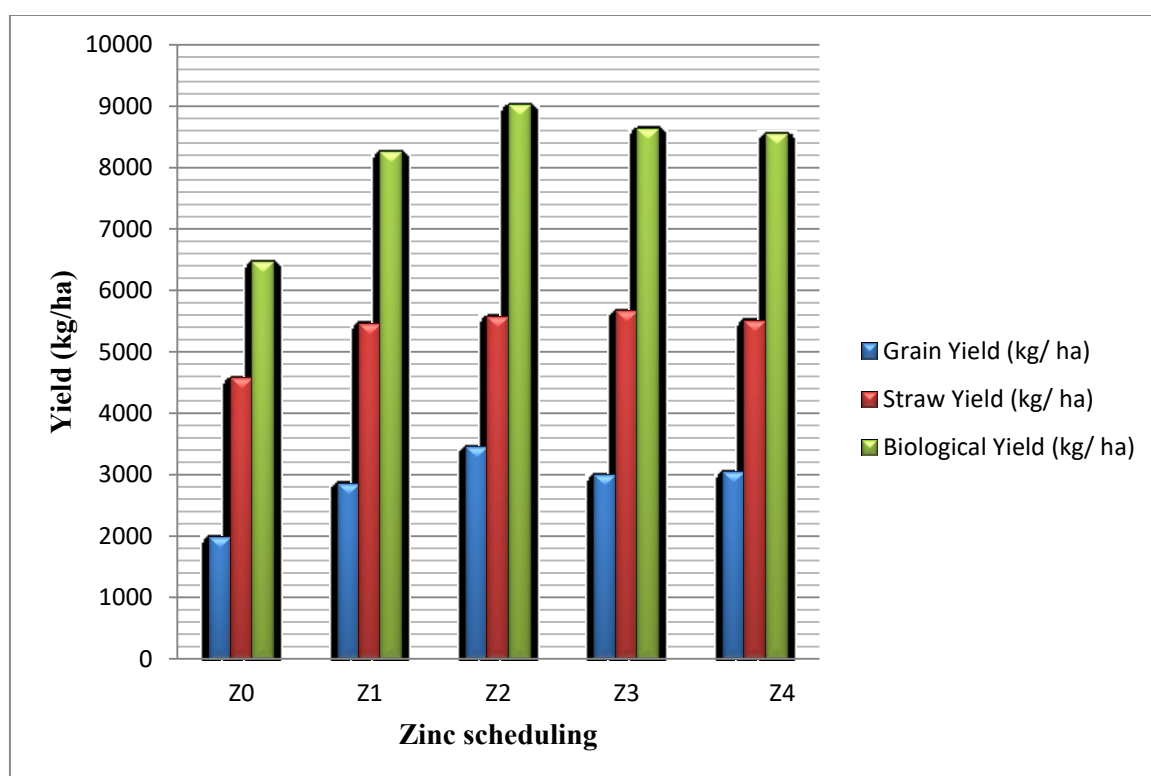


Fig 4.3(b): Effect of zinc scheduling on yield

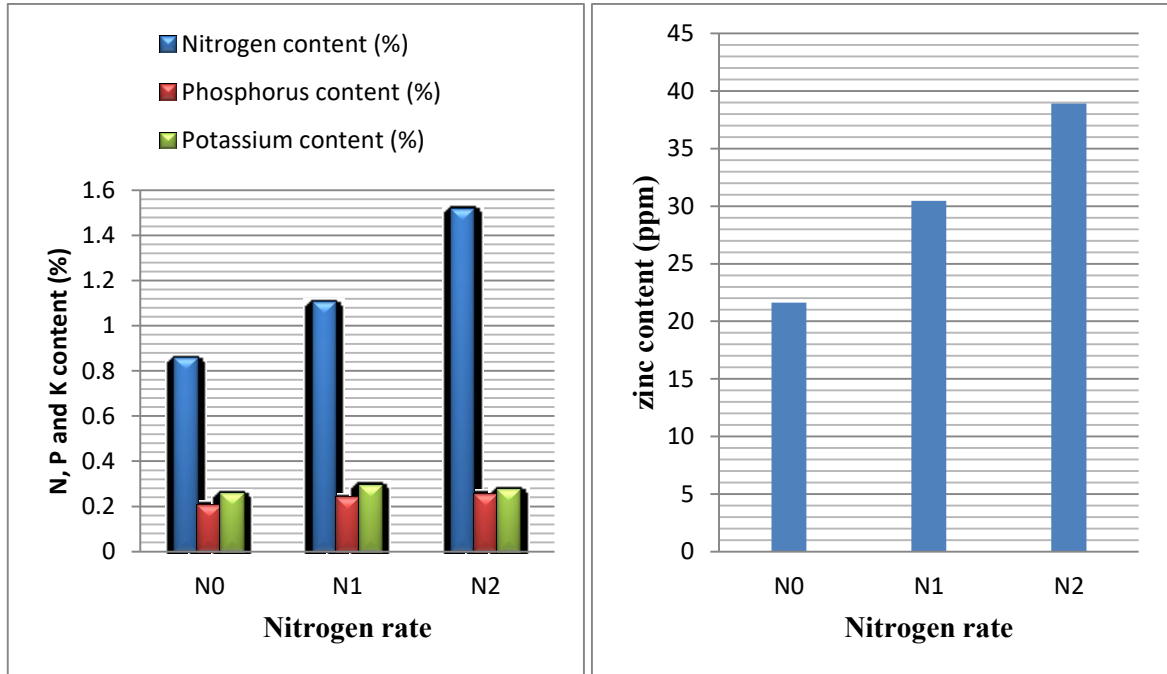


Fig 4.4(a): Effect of nitrogen rate on N, P, K and Zn content in grain

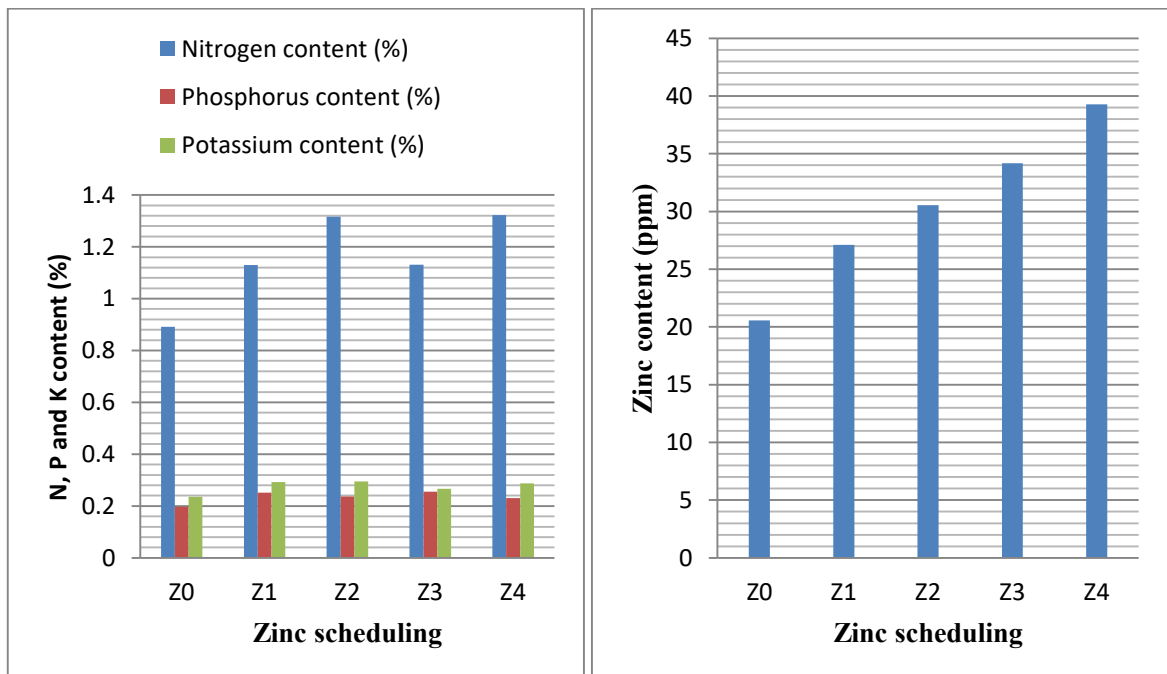


Fig 4.4(b): Effect of Zinc scheduling on N, P, K and Zn content in grain

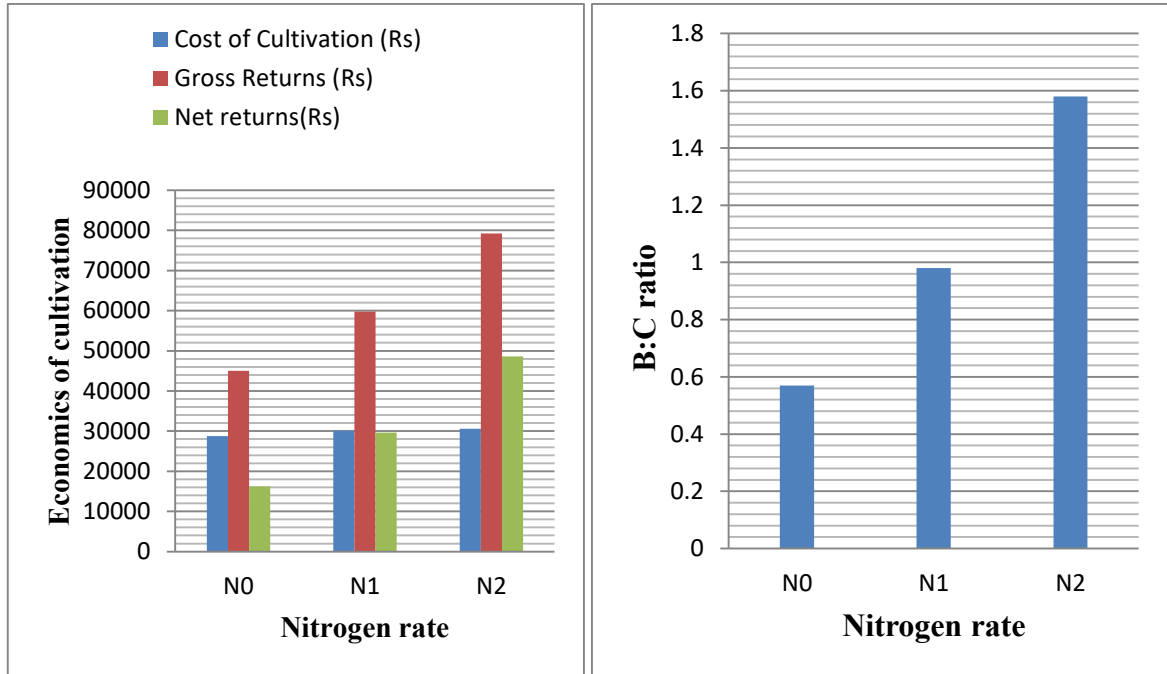


Fig 4.5(a): Effect of nitrogen rate on economics

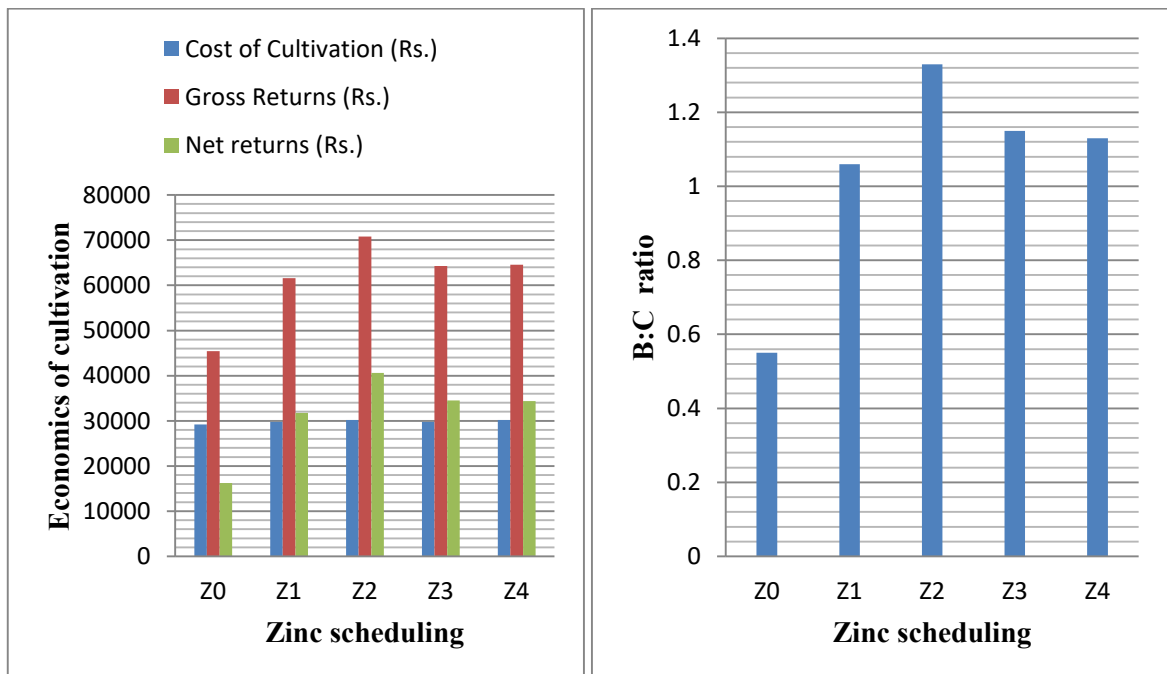


Fig 4.5(b): Effect of zinc scheduling on economics



- Layout and bunding of plot for sowing on 26/7/2015
- Seeds were broadcasted on puddled soil.



G 05



G 05

- Radical emerged from caryopsis
- broadcasting of seeds was done on 27/07/2015
- Dry Seed was soaked in water on 24/07/2015



G 09



G 09

- Imperfect leaf (prophyll) emerged at the tip of coleoptile
- This stage was recorded on 30/07/2015



G 10

- Tips of first true leaf visible
- This stage was come at 31.7.2015



G 10



G 11

- First leaf unfolded
- This stage was recorded on 1/8/2015



G 12

- Second leaf unfolded
- This stage was recorded on 3/8/2015



G 21

- First tiller detected
- This stage was recorded at 13/08/2015



G 21



G 22

- Main shoot and third tillers



G 22



G 30



G 30 (Source)

- Green ring stage
- 8-10 days before Panicle initiation stage



G 32



G 32

- Panicle formation
- Panicle 1-2 mm in length



G 34

- Panicle more than 2 mm long



G 34



G 58 & G 61

- 80% panicle emerged
- Anther visible at top of panicle (beginning of flowering)



G 58 & G 61



G 65

- Full flowering
- Anther visible at most spikelets



G 65



G 69

- Anthesis complete



G 69



G 77

- Noticeable increase in solids of liquid endosperm when crushing the kernel between fingers



G 77



G 85

- Soft dough
- Mealy ripe: kernels soft but dry



G 85



G 89



G 89

- Inflorescence losing chlorophyll
- Fingernail impression held



G 91

- Physiological maturity: no more dry matter accumulation.



Harvest stage

DISCUSSION

The results of the present investigation entitled “**Phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice**” conducted at the Agricultural Research Farm, Institute of Agriculture Sciences, B.H.U., Varanasi, during the kharif season of 2015 presented in the preceding chapter have been discussed and elucidated in this chapter with the help of suitable reasoning and evidences based on own observations during investigation and literatures available on the topic of investigation have been discussed in chapter to draw valid conclusions.

5.1 Effect of nitrogen

Nitrogen is the primary nutrient and plays vital role in growth as well as development of the plant. Deficiency of nitrogen in plant leads to stunted growth, appearance of a light green to yellow colors on the older leaves, starting from tips towards the base of leaf blade.

5.1.1 Growth attributes

Growth is the irreversible process occurs by cell division and cell elongation which leads to increases in plant biomass, weight and size of leaves and stems. Various growths attributes like plant height, tiller number, LAI, and yield of vegetative parts collectively determine the size of its photosynthetic apparatus, which in turn, results in the dry matter production and finally the productivity of the crop. Nitrogen is primary nutrient and a major constituent of cell, plays a vital role in cell division and elongation by virtue of being an integral part of diverse metabolically active compound like amino acids, proteins, nucleic acids, porphyrins, flavins, purines and pyrimidine's nucleotides, enzymes, co-enzymes and alkaloids. Therefore, it is vitally associated with the activity of every living cell.

The effect of nitrogen application on plant height was significant at all growth stage (Table 4.1.1). Application of nitrogen increased the plant height and significantly the tallest plant (91.02 cm) was recorded with application of 160 kg N/ha (N_2) at all growth stages of growth. This was might be due to rapid growth and development of plant cells due to adequate nitrogen supply to the growing plants. Secondly adequate supply of nitrogen resulted increase various metabolic process & performed better mobilization of synthesized carbohydrates in to amino acid and protein, which in turn stimulated the rapid cell division and cell elongation thus, allowed the plant to grow faster. This result has been confirmed by Paul *et al.* (2016), Puteh *et al.* (2014) and Jisan *et al.* (2014).

The total number of tillers was increase significantly with an increase in nitrogen fertilizer level. The maximum number of tillers (99.00) was recorded with N_2 (160 kg N/ha) at 60 DAS and thereafter, decreased. This was might be due to mutual competition among the plants for light, nutrients and other growth input resulting in mortality of tillers after 60 DAS. The highest tillers per running meter at 60 DAS might be due to higher availability of nutrient which facilitated proper synchronized tillering. This results are in close accordance to those of Paul *et al.* (2016) and Ali *et al.* (2014).

The value of SPAD is directly related to chlorophyll content in leaf. The value increased with increased age of the plant leaf and level of nitrogen. So, maximum value (35.20) of SPAD was recorded with 160 kg N/ha (N_2) at 60 DAS and lowest value was recorded with control (N_0). The chlorophyll content in leaf increase with increased level of nitrogen also reported by Puteh *et al.* (2014).

Leaf area index was significantly affected by different levels of nitrogen at different growth stage of crop. With increasing levels of nitrogen the leaf area index increased. Application of 160 kg N/ha (N_2) recorded significantly higher value (4.47) of leaf area index at 90 DAS as compared to lower rate at 30 DAS. This was might be attributed to more number of tillers per running meter and increased plant height, which ultimately increased the size and number of green-leaves due to more favorable utilization of nitrogen and, thus contributed to higher leaf area index. The lower leaf area index was obtained under lower rate of nitrogen which might be due to poor and

non-effective root system which resulted in reduced plant height and number of tillers per running meter and led to lower leaf area index. Similar type of result was also reported by Paul *et al.* (2016) & Ali *et al.* (2014).

Increasing levels of nitrogen positively affect the dry matter accumulation at all stage of crop. This might be due to increased plant height, leaf area index, improved tillering and increase in uptake of nutrients. The significantly maximum dry weight of shoots and root (g running m^{-1}) was recorded with 160 kg N/ha (N_2) at the all stage of observations. Similarly this type of result also reported by Azarpour *et al.* (2014).

Similarly increasing the level of nitrogen significantly increasing the crop growth rate (CGR) and relative growth rate (RGR) due to increasing level of nitrogen increase chlorophyll content in leaf resulted increase biomass accumulation per unit time and per unit weight of leaf. The maximum CGR (5.20) was obtained with 160 kg N/ha (N_2) at 90 DAS and maximum RGR (1.16) was obtained with 120 kg nitrogen /ha (N_1) 60 DAS. Similarly this type of result also reported by Azarpour *et al.* (2014); Kumar and Dawson (2013).

5.1.2 Yield attributes and yield

The economic yield of the rice depends upon the various yield attributes like effective tillers m^{-2} , length of the ear (cm), number of grains ear^{-1} and the test weight (g).

The maximum number of effective tillers ($71.07 \text{ running m}^{-1}$) was obtained with 160 kg N/ha (N_2). This was might be due to the fact that the number of tillers at this level of nitrogen was so high that even after mortality, it remained significantly higher than that of other levels of nitrogen and this consequently led to more number of panicle bearing tillers and panicle at this type of nitrogen management. Similar findings also reported by Puteh *et al.* (2014) and Devi and Sumathi (2013).

The panicle length was increase with increase nitrogen level, the highest panicles length (23.87) of rice was recorded N_2 (160 kg N/ha). The increase in length of panicle at this level of nitrogen might be attributed to better nutrition of panicle

primordial by better availability of nitrogen. Similarly this type of result also reported by Alim *et al.* (2008).

The maximum number of grain per panicle (112.67) was found with 160 kg N/ha (N_2). The number of grain panicle⁻¹ is generally associated with panicle length which was affected favorably due to levels and split application of nitrogen. This finding corroborates the finding of Puteh *et al.* (2014) & Devi and Sumathi (2013).

Mainly test weight of rice controlled by genetic makeup of the variety, though it increased significantly with 160 kg N/ha (N_2) and this may be due to better nutrition of spikelet's and is related to all other yield attributes. Similar type of result was also reported by Jisan *et al.* (2014).

Yield is the combine result of all growth and management factor. It is a well-known fact that grain yield is the function of more number of effective tillers per unit area, numbers of grain per panicle and test weight. As the yield is directly related to all the yield attributing characters which also showed increasing used with this type of nitrogen management. The treatment which had higher values of these characters had maximum yield, and these characters were more with highest level of nitrogen with 160 kg N/ha (N_2). Positive grain yield may be due to nitrogen being a major nutrient, affected all physic-chemical process. The similar result was reported by Dubey *et al.* (2016).

Harvest index was also affected with increase in nitrogen level, the maximum harvest index (37.29%) was found with 160 kg N/ha (N_2). This may be due to higher grain yield as compared all other treatments. This result also supported by Jisan *et al.* (2014).

5.1.3 Nutrients content and uptake

Nitrogen content (%) of grain and straw and its uptake as affected by nitrogen application significantly. The highest value (1.16%) was recorded with N_2 (160 kg nitrogen/ha) in grain. This was may be due to the increasing levels of nitrogen and split application. Devi and Sumathi (2011) also reported the highest protein content in

grain with increasing levels of nitrogen. The similar result was also reported by Singh and Tripathi (2007) reported that the increase N uptake and protein content with increase nitrogen rate up to 160 kg N ha⁻¹.

Nitrogen content in straw was increase with nitrogen levels the maximum observation (0.58%) found with 160 kg N/ha (N₂) this may be due to maximum levels of nitrogen and split application during vegetative growth stage. The similar kind of result also reported by Nori *et al.*(2008).

Total nitrogen uptake by rice plant significantly influence by nitrogen levels. The maximum nitrogen uptake (97.51 kg ha) was obtained with 160 kg N/ha (N₂). The similar result was also reported by Nori *et al.* (2008).

5.2 Effect of zinc

It is clear from the results presented in previous chapter that zinc management evinced favorable effect on growth parameters *viz.* plant height, number of leaves, number of tillers, leaf area index and dry matter production during the year of experimentation. The improvement in growth characters might be due to presence of zinc as it has vital role in many important enzyme systems. Zinc is essential for amino acid and favoured assimilation of protein and carbohydrates metabolism. These two compounds when presented in meristematic region of the plant induce rapid cell division and elongation, which ultimately results in better crop growth and development (Zhao *et al.* 2011; Rehman *et al.* 2012).

5.2.1 Growth attributes

The effect of basal and foliar application of zinc on plant height was influence significantly and the maximum plant height (84.55 cm) was observed with Z₂ at 90 DAS. This may be due to application of zinc at late booting and anthesis. Zn-induced availability of growth regulators such as gibberellins, kinetin, and indole-3-acetic acid and enhancement in the ability of plant to cope with an adverse environment. The similar result was recorded by Arif *et al.* (2016).

Basal and foliar application of zinc significantly influenced number of tillers/running meter at all growth stage. The highest (99.33) tillers /running meter obtained with Z_2 at 60 DAS. This may be also same region as plant height. This type of observation also reported by Gour *et al.* (2015) & Rana and Kasim (2014).

Chlorophyll content in the leaves also influenced by foliar application of zinc at different growth stage. This indicated by SPAD value, the maximum SPAD value (32.96) was observed with Z_2 at 60 DAS. This may be due to positive interaction between nitrogen and zinc. This type of result also reported by Arif *et al.* (2016).

Leaf area index was influenced significantly by zinc foliar application. The maximum leaf area index (3.36) was observed with Z_2 at 90 DAS. This may be also due to positive interaction between nitrogen and zinc. The similar result was also recorded by Shivay *et al.* (2012); Keram *et al.* (2012).

The dry matter accumulation (g running m^{-1}) of rice also significantly increased with the advancement of the crop growth stage. The maximum shoot dry weight ($200.78 \text{ g running m}^{-1}$) was observed with Z_2 at harvest stage and the maximum root dry weigh ($78.43 \text{ g running m}^{-1}$) was observed with Z_3 at 90 DAS. The cause of this effect may be due to that this rate produced significantly maximum height, tiller number per plant and highest chlorophyll content which invariably leads to higher dry matter. This finding has been supported by Boochuay *et al.* (2013).

Crop growth rate (CGR) and relative growth rate (RGR) were also influenced by zinc application as nitrogen application. The maximum CGR ($4.49 \text{ g running m}^{-1}\text{day}^{-1}$) and RGR ($1.15 \text{ g g}^{-1} \text{ day}^{-1}$) were recorded with Z_2 at 90 DAS. Similarly this type of result also reported by Boonchuay *et al.* (2013) and Muthukumararaja and Sriramachandrasekharan (2012).

5.2.2 Yield attributes and yield

The number of effective tillers per running meter was significantly influence by zinc application. The maximum effective tillers (66.89) were observed with Z_2 . These may be due to contribution of zinc in plant growth. The similar kind of result was recorded by Yin *et al.* (2016).

The length of panicle influenced significantly by zinc application. The maximum panicle length (24.16 cm) was recorded with Z_3 . The increase in length of panicles attributed to better zinc nutrition of panicle primodia. Similarly this type of result also reported by Shehzad *et al.* (2012).

The number of grain per panicle influence significantly by zinc foliar allocation. Maximum grain (105.89) per panicle was recorded with Z_2 is generally associated with panicle length which was also affected significantly by application of this treatment. These findings corroborate the finding of Jana *et al.* (2009).

Similarly the weight of panicle was influenced significantly as panicle length by application of zinc; maximum panicle weight (2.57 gram) was recorded with Z_2 . This may be due zinc play role for plant growth and development finally dry matter accumulation. Jana *et al.* (2009) also reported this type of observation.

Test weight significantly influenced by zinc application, the maximum test weight (23.66 gram) was obtained with Z_2 . This may be due to application at late booting and anthesis increase growth attributes finally test weight also increase. Similar type of result also recorded by Muthukumararaja and Sriramach and Rasekharan (2012).

Grain and straw yield of rice significantly affected by zinc fertilization, the maximum grain yield (3442.59 kg/ha) was recorded with Z_2 and maximum straw yield (5658.50 kg/ha) was recorded with Z_3 . The increasing of grain yield may be due to yield of a crop directly related with the growth and yield attributes of the crops. It also might be due to the fact that zinc application after booting stage leads to increase the zinc content in the grains but not increase the yield of the crop. Similarly this type of result also reported by Dubey *et al.* (2016).

5.2.3 Nutrients content and uptake

The content (mg) of zinc in grain and straw and its uptake was influenced significantly. The significantly maximum zinc content (39.29 mg kg^{-1}) in grain and (78.67) in straw was recorded with Z_4 . Recorded zinc content in straw higher than grain may be due to poor mobilization ability of zinc in grain (physiological

inactiveness of zinc) from straw. Maximum zinc content in grain was obtained when zinc was applied by foliar at inflorescence emerged and early milk. It may be due to maximum translocation of zinc occurring from source to sink. These findings corroborate the finding of Yin *et al.* (2016) & Poonia *et al.* (2014).

Zinc content in straw (78.67 mg) also reported significantly higher with Z₄. This might be attributed with maximum zinc absorption by foliar part when zinc was applied during dough stage.

The maximum total zinc uptake (0.569 kg/ha) was reported with Z₄. The similar result also reported by Pooniya *et al.* (2014).

5.3 Nitrogen and zinc interaction

In the present study, the interaction effect of nitrogen and zinc were observed no of tillers running m⁻¹ at harvest, LAI at 30 and 60 DAS, shoot dry matter accumulation (g running m⁻¹) at 60, 90 DAS and at harvest, root dry matter accumulation (g running m⁻¹) at 30, 60 DAS, crop growth rate at 60 and 90 DAS, relative growth rate at 60 and 90 DAS, effective tillers, grain per panicle, panicle weight (g), test weight (g), grain yield (Kg ha⁻¹), straw yield (Kg ha⁻¹), biological yield (kg ha⁻¹), nitrogen (%), phosphorus (%), potassium (%) and zinc content (mg) in grain, nitrogen uptake by grain and straw, potassium uptake by straw and zinc uptake in grain, total nitrogen, potassium and zinc uptake, partial factor productivity of N and Zn, agronomic efficiency of N and Zn, recovery efficiency of N and Zn, protein content in grain and protein yield. This may be due to fulfill the requirement of nitrogen and zinc nutrition and also might be due to the positive interaction nitrogen and zinc. The maximum values were observed with 160 kg N/ha + 10 kg Zn at basal+ 0.3% ZnSO₄ spray at g 45 (late booting) + 0.3% ZnSO₄ spray at G 61 (anthesis) (N₂Z₂). This finding was supported Ali *et al.* (2014), Masum *et al.* (2013).

5.4 Economics

The cost of cultivation was influenced markedly under different treatment by nutrient application and source of fertilizer. The gross return, which is related the

yield of crop and its market price, differed noticeably under different treatments and this accompanied with cost of cultivation influenced the overall net return and B: C ratio.

As about the application of nitrogen, the gross return, net returns and benefit: cost ratio of 79231.12 ₹ha⁻¹, 48624.94 ₹ha⁻¹ and 1.58 respectively which was found significantly maximum with the application of 160 kg N/ha (N₂). This might be due to the fact that the entire yield attributes and ultimately grain yield and straw yield found significantly maximum than all other nitrogen treatments, which leads to the maximum gross return, net returns and benefit: cost ratio although cost of cultivation was also higher in these treatments.

There was significantly maximum gross return (70781.12 ₹ha⁻¹) found with Z₂. This might be due to highest yield from this treatment as compared to all other treatments, although the cost of cultivation was higher but the higher yield compensated this. In case of net return and B:C ratio same trend also followed and significantly maximum net return (40585.52 ₹ha⁻¹) and B:C ratio (1.33) found with Z₂. This type of result may be due to higher yield.



SUMMARY AND CONCLUSION

The present investigation entitled “**phenophase (BBCH scale) based nitrogen and zinc scheduling for yield and zinc biofortication in direct seeded rice**” was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India during kharif (rainy) season of 2015 with a view to test the performance of nitrogen and zinc fertilization on growth, yield and zinc content of rice under eastern Uttar Pradesh condition to suggest better management of nitrogen and zinc fertilizer.

The soil of the experimental field was sandy clay loam in texture with pH 7.2. It was moderately fertile, low in available organic carbon (0.42%), available nitrogen (199.0 kg ha^{-1}), available Zn (0.50 mg/kg) and medium in available phosphorus (24.64 kg ha^{-1}) and potash ($210.50 \text{ kg ha}^{-1}$). The factorial experiment was laid out in randomized complete block design (factorial) with three levels of nitrogen viz. 0 kg N ha^{-1} (control), 120 kg N ha^{-1} [50% at sowing +25% at G 21 (1 tiller detected) +25% at G 32 (panicle formation; panicle 1-2 mm long)], 160 kg N ha^{-1} [50% at sowing +25% at G 21 (1 tiller detected) +25% at G 32 (panicle formation; panicle 1-2 mm long)] and five types of zinc management *i.e.* control (Z_0), 5 kg Zn/ha at basal + 0.3 % ZnSO_4 spray at G 45 (late booting) + 0.3% ZnSO_4 spray at G 61 (anthesis; anther visible at top of panicle), 10 kg Zn/ha at basal + 0.3% ZnSO_4 spray at G 45 (late booting) + 0.3% ZnSO_4 spray at G 61 (anthesis; anther visible at top of panicle), 5 kg Zn/ha at basal +0.3% ZnSO_4 spray at G 51 (tip of inflorescence emerged)+ 0.3% ZnSO_4 spray at G 73 (early milk), 10 kg Zn/ha at basal +0.3% ZnSO_4 spray at G 51 (tip of inflorescence emerged)+0.3% ZnSO_4 spray at G 73 (early milk) and replicated thrice. Recommended dose of $\text{P}_2\text{O}_5\text{-K}_2\text{O}$ ($60\text{-}40 \text{ kg ha}^{-1}$) was applied. The rice variety HUR 3022 was sown in puddled soil with row to row spacing of about 20 cm.

Various observations were recorded during the course of investigation including different phonological stages, growth attributes, yield attributes, yields,

nitrogen and zinc content as affected by nitrogen and zinc fertilizer. Growth parameters were recorded at different growth stages such as 30, 60, 90 DAS and at harvest. The growth attributes included plant height, number of tillers, SPAD value, dry matter accumulation and leaf area index (except at harvest). Similarly yield attributes *viz.*, effective tillers, panicle length (cm), panicle weight (g), number of grains per panicle and test weight, grain, straw, biological yields, and harvest index was recorded. The nutrient content such as N, P, K, and Zn content and its total uptake, protein content and protein yield were also noted to assess the effect of treatments.

The data observed during the experimentation were subjected to statistical analysis to drawn genuine outcomes. Finally, the different treatments were analyzed for their net return and benefit: cost ratio (B:C ratio). The important findings and comprehensive outcome emerging from the examinations has been summarized here under.

1. Plant height was significantly influenced by nitrogen levels and maximum plant height of 53.80, 75.11, 91.02, 90.20 cm was recorded with 160 kg N ha⁻¹ (N₂) at 30, 60, 90 DAS and at harvest respectively. Zinc application had also significant impact on plant height and maximum plant height (84.55 cm) was recorded with 10 kg ZnSO₄/ha at basal + 0.3% ZnSO₄ spray at G 45 (late booting) + 0.25% ZnSO₄ spray at G 61 (anthesis; anther visible at top of panicle) (Z₂).
2. Nitrogen significantly influenced the number of tillers (running m⁻¹) at different growth stages. Maximum number of tillers (97.00 running m⁻¹) was recorded at 60 DAS with 160 kg N ha⁻¹. Zinc application also influenced tillers number and maximum tillers (99.33 running m⁻¹) were recorded with 10 kg ZnSO₄/ha at basal + 0.3% ZnSO₄ spray at G 45 (late booting) + 0.25% ZnSO₄ spray at G 61 (anthesis; anther visible at top of panicle) (Z₂). Nitrogen levels and zinc scheduling was significantly interact with each other at the time of harvesting and maximum number of tillers (96.67 running m⁻¹) was recorded with N₂Z₂ at harvest.

3. Nitrogen fertilizer significantly affects the SPAD value at all the growth stages. The maximum SPAD value (35.20) was recorded with N₂. Zinc had significant effect the SPAD value and maximum SPAD value (32.96) was recorded with Z₂ at 60 DAS.
4. Nitrogen significantly affects the LAI at all the growth stages the maximum LAI (4.47) was recorded at 90 DAS with N₂. Zinc had significantly affect the LAI and maximum LAI was recorded with (3.36) with Z₂. N and Zn interaction was recorded at 30 and 60 DAS. Maximum LAI was (4.14) recorded with N₂Z₃ at 60 DAS.
5. Shoot dry matter accumulation (g running m⁻¹) was significantly influenced by nitrogen application and maximum dry matter accumulation (235.53 g running m⁻¹) was recorded with N₂. Zinc has also influences the shoot dry weight accumulation and maximum (200.78 g running m⁻¹) was recorded with Z₂. However, N and Zn interaction was recorded at 60, 90 DAS and at harvest stage. Maximum dry matter accumulation was (268.45) recorded with N₂Z₄ at harvest.
6. Nitrogen significantly influenced the root dry matter accumulation (g running m⁻¹) at all growth stages. The maximum root dry matter accumulation (83.70 g running m⁻¹) was recorded with N₂ at 90 DAS. Zinc has also influences the root dry weight accumulation and maximum (78.43 g running m⁻¹) was recorded with Z₃. However, N and Zn interaction was recorded at 30 and 60 DAS.
7. CGR was significantly influence by nitrogen levels at different growth stages. Maximum CGR (5.199 g running m⁻¹ day⁻¹) was recorded with N₃ at 90 DAS. Zinc application had also significant impact on CGR and maximum CGR (4.664 g running m⁻¹ day⁻¹) was recorded with Z₂. Nitrogen and zinc fertilizer significantly interact at 60 and 90 DAS.
8. RGR was significantly influence by nitrogen levels at different growth stages. Maximum RGR (1.158 g g⁻¹ d⁻¹) was recorded with N₂ at 60 DAS. Zinc

application had also significant impact in RGR and maximum RGR ($1.148 \text{ g g}^{-1} \text{ d}^{-1}$) was recorded with Z_2 .

9. Nitrogen levels significantly affect the number of effective tiller (running m^{-1}) and maximum number of effective tiller running m^{-1} (71.07) was recorded with N_2 . Zinc application had also significant effect on number of effective tiller running m^{-1} and maximum number of tiller running m^{-1} (66.89) was recorded with Z_2 . Nitrogen levels and zinc application significantly interact with each other for production of effective tillers and maximum number tiller (96.67) was recorded with N_2Z_2 .
10. Nitrogen levels significantly affect the panicle length and maximum (23.87 cm) was recorded with N_2 . Zinc application had also significant effect on panicle length and maximum (24.16 cm) was recorded with Z_3 .
11. Grains panicle $^{-1}$ was significantly influenced by nitrogen levels and maximum grains panicle $^{-1}$ (112.67) was recorded with N_2 . Zinc application had also significant effect on grains panicle $^{-1}$ and maximum grain panicle $^{-1}$ (105.89) was recorded with Z_2 .
12. Nitrogen levels significantly affect the test weight (g) and maximum test weight (23.53 g) was recorded with N_2 . Zinc application had also significant effect on test weight and maximum test weight (23.66 g) was recorded with Z_2 .
13. Panicle weight (g) was significantly influenced by nitrogen levels and maximum panicle weight (2.76 g) was recorded with N_2 . Zinc application had also significant effect on panicle weight (g) and maximum (2.57 g) was recorded with Z_2 . The significant interaction between nitrogen levels and zinc application was recorded and maximum panicle weight (3.13 g) was recorded with N_2Z_3 .
14. Grain yield was significantly influenced by nitrogen levels and maximum grain yield ($3817.71 \text{ kg ha}^{-1}$) was recorded with N_2 . Zinc application had also significant effect on grain yield and maximum grain yield ($3442.59 \text{ kg ha}^{-1}$)

- was recorded with Z_2 . Combination of N and Z also showed interaction and maximum grain yield ($4612.08 \text{ kg ha}^{-1}$) was recorded with N_2Z_2 treatment.
15. Nitrogen levels significantly affect the straw yield and maximum straw yield ($6384.94 \text{ kg ha}^{-1}$) was recorded with N_2 . Zinc application had significant effect on straw yield and maximum straw yield ($5658.50 \text{ kg ha}^{-1}$) was recorded with Z_3 . Combination of N and Z also showed interaction and maximum straw yield ($6916.63 \text{ kg ha}^{-1}$) was recorded with N_2Z_2 treatment
 16. Biological yield was significantly influenced by nitrogen levels and maximum ($10202.98 \text{ kg ha}^{-1}$) was recorded with N_2 . Zinc application had also significant effect on biological yield and maximum ($9010.17 \text{ kg ha}^{-1}$) was recorded with Z_2 . The significant interaction between nitrogen levels and zinc application was recorded and maximum biological yield ($11528.70 \text{ kg ha}^{-1}$) was recorded with N_2Z_2 .
 17. Nitrogen content in grain was significantly influenced by nitrogen levels and maximum nitrogen content (1.52 %) was recorded with N_3 . Zinc application had also significant effect and maximum nitrogen content (1.32%) was recorded with Z_4 . The significant interaction between nitrogen levels and zinc application was recorded and maximum nitrogen content in grain (1.81%) was recorded with N_2Z_4 .
 18. Nitrogen levels significantly affect the zinc content in grain and maximum (38.92 mg) was recorded with N_2 . Zinc application had also significant effect and maximum zinc content (39.29 mg) was recorded with Z_4 . N and Zn significantly interact for zinc content in grain and maximum (51.56 mg) was recorded with N_2Z_4 combination.
 19. Nitrogen levels significantly affect the nitrogen uptake in grain and maximum (60.17 kg ha^{-1}) was recorded with N_2 . Zinc application had also significant effect on nitrogen uptake and maximum (47.97 kg ha^{-1}) was recorded with Z_2 . Combination of $N \times Zn$ also showed interaction effect on nitrogen uptake and maximum nitrogen uptake in grain (79.91 kg ha^{-1}) was recorded with N_2Z_4 .

20. Nitrogen levels significantly affect the zinc uptake in grain and maximum (0.16 kg ha^{-1}) was recorded with N_2 . Zinc application had also significant effect on zinc uptake and maximum (0.13 kg ha^{-1}) was recorded with Z_4 . $N \times Z$ also showed interaction effect on zinc uptake and maximum (0.23 kg ha^{-1}) was recorded with combination of N_2Z_4 .
21. Partial factor productivity of nitrogen was significantly influence by nitrogen levels and maximum ($23.86 \text{ kg grain kg}^{-1}$ of nitrogen) was recorded with N_2 . Zinc application had also significant effect on partial factor productivity (kg grain kg^{-1} of zinc) of zinc and maximum ($498.47 \text{ kg grain kg}^{-1}$) was recorded with Z_3 . Nitrogen levels and zinc application was interact significantly to each other, and maximum partial factor productivity of nitrogen ($28.83 \text{ kg grain kg}^{-1}$) was recorded with N_2Z_2 . Maximum partial factor productivity of zinc ($658.32 \text{ kg grain kg}^{-1}$) was recorded with N_2Z_1 .
22. Nitrogen levels significantly affect the agronomic efficiency (kg grain kg^{-1}) of nitrogen and maximum ($13.75 \text{ kg grain kg}^{-1}$) was recorded with N_2 . Zinc application had also significant effect on agronomic efficiency and maximum ($228.49 \text{ kg grain kg}^{-1}$) was recorded with Z_3 .
23. Recovery efficiency (%) of nitrogen was significantly influence by nitrogen levels and maximum (45.02 %) was recorded with N_2 . Zinc application had also significant effect on recovery efficiency (%) of zinc and maximum (6.23%) was recorded with Z_3 .
24. Nitrogen levels significantly affect the nutrient harvest index (%) and maximum (60.54%) was recorded with N_2 . Significantly difference of zinc harvest index was not observed with zinc application.
25. Physiological efficiency (kg grain kg^{-1}) of nitrogen was significantly influence by nitrogen levels and maximum ($39.70 \text{ kg grain kg}^{-1}$) was recorded with N_1 . Zinc application had also significant effect on physiological efficiency (kg grain kg^{-1} of zinc) of zinc and maximum ($5393.22 \text{ kg grain kg}^{-1}$ zinc uptake) was recorded with Z_2 .

26. Nitrogen levels significantly affect the protein content (%) in grain and maximum (9.48%) was recorded with N₂. Zinc application had also significant effect on and maximum (8.27%) was recorded with Z₄. Combination of N × Z also showed significant interaction effect on protein content (%) in grain and maximum was recorded (11.31%) with N₂Z₄.
27. Protein yield (kg ha⁻¹) was significantly influenced by nitrogen application and maximum (376.06 kg ha⁻¹) was recorded with N₂. Zinc application had also significant effect and maximum (299.78 kg ha⁻¹) was recorded with Z₂. Combination of N × Zn also showed interaction maximum (499.42 kg ha⁻¹) protein yield was recorded with N₂Z₄ treatment.
28. Nitrogen levels significantly affect the gross return and maximum (₹79231.12 ha⁻¹) was recorded with N₂. Zinc application had also significant effect on and maximum (₹70781.12 ha⁻¹) was recorded with Z₂.
29. Nitrogen levels significantly affects the net return and maximum (₹48624.94 ha⁻¹) was recorded with N₂. Zinc application had also significant effect on net return and maximum (₹40585.52 ha⁻¹) was recorded with Z₂.
30. Nitrogen levels had significantly affected the B: C ratio and maximum (1.58%) was recorded with N₂. Zinc application had also significant effect on B: C ratio and maximum (1.33 %) was recorded with Z₂.

Conclusions

Since the experiment was conducted only for one crop season, no valid conclusion can be drawn. However, On the basis of experimental findings, the following broad conclusions can be drawn:

On the basis of one year field experimentation it may be concluded that independent application of 160 kg N/ha and 10 kg Zn/ha at basal + 0.3% ZnSO₄ spray at G 45 (late booting) + 0.3% ZnSO₄ spray at G 61 (anthesis; anther visible at top of panicle) is recommended as these treatments fetched significantly higher grain yield, net returns and B:C ratio from direct seeded rice. However, application of 160 kg

N/ha and 10 kg Zn/ha at basal +0.3% ZnSO₄ spray at G 51 (tip of inflorescence emerged) + 0.3% ZnSO₄ spray at G 73 (early milk) of crop recorded maximum zinc content.

There was significant interaction effect of nitrogen and zinc for higher grain yield with N₂Z₂ [160 kg N/ha and 10 kg Zn/ha at basal + 0.3% ZnSO₄ spray at G 45 (late booting) + 0.3% ZnSO₄ spray at G 61 (anthesis; anther visible at top of panicle)] and for nitrogen and zinc content in grain N₂Z₄ [(160 kg N/ha and 10 kg Zn/ha at basal +0.3% ZnSO₄ spray at G 51 (tip of inflorescence emerged)+ 0.3% ZnSO₄ spray at G 73 (early milk)].

However, these results are only indicative and require further experimentation to arrive at some consistent and final conclusion.



BIBLIOGRAPHY

- Ahmad, S., Humphrey, E., Salim, M., Chauhan, BS. (2015) Growth, yield and nitrogen use efficiency of dry-seeded rice as influenced by nitrogen and seed rates in Bangladesh. *Field Crop Research*. 186(2016): 18-31
- Alagesan, A. and Raja, BC. (2011) Impact of different nitrogen level and time of application on grain yield and yield attributes of wet seeded rice. *International Journal of Food, Agriculture and Veterinary Sciences*. **1**(1): 35-41.
- Ali, H., Hasnain, Z., Shahzad, A. and Ahmad, N. (2014) Nitrogen and Zinc interaction improves yield and quality of submerged basmati rice (*Oryza sativa* L.). *Notulae Botanicae Horti Agrobotanici Cluj- Napoca*. **42** (2): 372-379.
- Alim, MA., Paul, NK. and Begum, MS. (2008) Different nitrogen sources and their doses on grain growth and yield of Boro rice. *International Journal of Sustainable Agricultural Technology*. **4** (4):49-54.
- Ameen, A., Aslam, Z., Zaman, Q.Z., Ehsanullah, Zamir, S.I., Khan, I., Subhani, M.J. (2014) Performance of Different Cultivars in Direct Seeded Rice (*Oryza sativa* L.) with Various Seeding Densities. *American Journal of Plant Sciences*. **5**: 3119-3128.
- AOAC (Association of Official Agricultural chemist) (1970) Methods of Analysis, 11th education conference Washington, DC. 18-19.
- Arif, M., Shehzad, MA., Bashir, F., Tasneem, M., Yasin, G., and Iqbal, M., (2012) Boron, zinc and microtome effects on growth, chlorophyll contents and yield attributes in rice (*Oryza sativa* L.) cultivar. *African Journal of Biotechnology*. **11**(48):10851-10858.
- Azarpour, E., Moraditochae, M. and Bozorgi, HR. (2014) Effect of nitrogen fertilizer management on growth analysis of rice cultivars. *International Journal of Biosciences*. **4**(5):35-47.
- Boonchuay, P., Cakmak, I., Benjavan, R. and Chanakan, PU. (2013) Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. *Soil Science and Plant Nutrition*. **13** (10): 1-9.
- Bouyoucos, GJ. (1962) Hydrometer method for making particle size analysis of soil. *Agronomy Journal*. **54**: 464-465.
- Cakmak, I. (2008) Enrichment of cereal grains with zinc: Agronomic or genetic biofortification. *Plant and Soil*. **302**: 1-17.
- Cao, Y., Tian, X., Yang, X., Lu, X., Chen, H., Nan, X. and Li, X. (2010) Effects of soil and foliar application of Zn on winter wheat grain Zn concentration and bioavailability. *Plant Nutrition and Fertilizer Science*. **16** (6): 1394-1401.

- Chakrabarti, N. and Mukherji, S. (2002) Growth-regulator-mediated changes in leaf area and metabolic activity in mungbean under stress conditions. *Indian Journal of Plant Physiology*. **7**: 256–263.
- Chandel, G., Banerjee, S., See, S., Meena, R., Sharma, DJ. and Verulkar, SB. (2010) Effects of different nitrogen fertilizer levels and native soil properties on rice grain Fe, Zn and protein contents. *Rice Science*. **17** (3): 213–227.
- CRRI (2014) CRRI Annual Report 2013-14 Central Rice Research Institute, Cuttack.
- Das, RK., Singh, JP. and Prasad, SK. (2009) Effect of nitrogen and potassium levels on growth and yield of hybrid rice (*Oryza sativa* L.). *Environment and Ecology*. **27** (1A): 430-432.
- Data, K. S., Varma, S. K., Angrish, R., Kumar, B. and Kumari, P. (2004) Alleviation of salt stress by plant growth regulators in *Triticum aestivum* L. *Biologia Plantarum*. **40**: 269–275.
- Devi, MG. and Sumathi, V. (2011) Effect of nitrogen management on growth, yield and quality of scented rice (*Oryza sativa* L.) under aerobic conditions. *Journal of Research ANGRAU*. **39**(3): 81-83.
- Donald, CM. and Hamblin, J. (1976) The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Advances in Agronomy*. **28**: 361-445.
- Dubey, SK., Tiwari, DD., Pandey, SB., Singh, UN, Katiyar, NK. (2016) Effect of nitrogen, sulphur and zinc application on yield, nutrient uptake and quality of rice. *Research on Crops* **17** (1): 13-15.
- Duxbury, R. K. Gupta, and R. J. Buresh, Eds.), pp. 149–172, ASA Special Publication Number 65. ASA-CSSA-SSSA, Madison, Wisconsin, USA.
- Dwivedi, AP., Dixit, RS and Singh, GR (2006) Effect of nitrogen, phosphorus and potassium levels on growth, yield and quality of hybrid rice (*Oryza sativa* L.). *Oryza*. **43**(1):64-66.
- Fageria, NK., Moreira, A. and Coelho, AM. (2008) Yield and yield components of upland rice as nitrogen fertilization. *Communications in Soil Science and Plant Analysis*. **42**:1719-1727.
- Fang, F., Wang, L., Zhihong, X., Liyan, Z., Xinxin, A. and Qiuhui, Hu. (2008) Effect of foliar application of zinc, selenium, and iron fertilizers on Nutrients Concentration and yield of rice grain in China. *Journal of Agriculture and Food Chemistry*. **56**(6): 2079–2084.
- FAO, 2014. Food and Agriculture Organization of the United Nations Statistics Division <http://faostat.fao.org/download/Q/QC/E>.
- Faraji, F., Esfehiani, M., Kavoosi, M., Nahvi, M. and Rabiyyi. B. (2012) Effects of split application and levels of nitrogen fertilizer on growth indices and grain yield

- of rice (*Oryza sativa* cv. Khazar). *Iranian Journal of Field Crop Science*. **43**(2): 323-333.
- Farooq, M. Siddique, KHM. Rehman, H. Aziz, T. Dong-Jin, Lee. and Wahid, A. (2011) Rice direct seeding: Experiences, challenges and opportunities. *Soil Tillage Research*. **111**: 87–98.
- Fei, X., Zhong, W., Jie, Y., Gang, C. and Peng, Z. (2008) Effects of nitrogen application time on caryopsis development and grain quality of rice variety Yangdao 6. *Rice Science*. **15**(1): 57–62
- Fenner, M., (1998) The phenology of growth and reproduction in plants. *Perspectives in Plant Ecology, Evolution and Systematics*. **1**/1, pp. 78–91
- Ghulam, ME., Khan, AI., Chattha, HZ., Trethowan, AAR. And Chattha , BM. (2011) Effect of method and time of zinc application on growth and yield of rice (*Oryza sativa* L.). *International Journal for Agro Veterinary and Medical Sciences (IJAVMS)*. **5**(6): 530-535.
- Gill, GS., and Wallia, SS. (2013) Effect of establishment methods and nitrogen levels on basmati rice (*Oryza sativa*). *Indian Journal of Agronomy*. **58** (4): 506 -511
- Gomez, AK. (1972) Technique for field experiments with rice. *International Rice Research Institute*, Los Bans, Philippines, pp37-38.
- Gomez, AK. and Gomez, AA.(1984) Statistical procedure for agricultural research, second Edition, *A Willey- International Science Publication, John Wiley and Sons*, New Delhi, India, pp 680.
- Gour, SP., Singh, SK., Lal, R., Bohra, JS., Srivastava, JP., Singh, SP., Kumar, M., Kumar, O., Latore, AM. (2015) Effect of organic and inorganic sources of plant nutrients on growth and yield of rice (*Oryza sativa* L.) and soil fertility. *Indian Journal of Agronomy* **60** (2): 328-331
- Graham R D, Senadhira D, Beebe S, Iglesias C, Monasterio I. (1991) Breeding for Micronutrient density in edible portion of staple food crop: Conventional approaches. *Field Crops Research*. **60**: 57-80.
- Guo, Z., Khoshgoftarmanesh, AH., Afyuni, M. and Hadadzadeh, H. (2014) The effectiveness of foliar applications of synthesized zinc-amino acid chelates in comparison with zinc sulfate to increase yield and grain nutritional quality of rice. *European Journal of Agronomy*. **45**: 68-74.
- Haque, MM., Saleque, MA., Shah, AL., Biswas, JC., Kim, P. (2015) Long-term effects of sulfur and zinc fertilization on rice productivity and nutrient efficiency in double rice cropping paddy in Bangladesh. *Communications in Soil Science and Plant Analysis*. **46**(22) 2877-2887
- Hatamifar, B., Ashoury, M., Shokri-Vahed, H. and Rokhsar, PS., (2013) Effects of irrigation and various rates of nitrogen and potassium on yield and yield

- components of rice plant (*Oryza sativa* L.). *Persian Gulf Crop Protection*. **2** (2):19-25.
- Hay, RK. and Walker, AJ. (1989) Introduction to the physiology of crop yield influenced by nitrogen sources. *Journal of Plant Nutrition*. **34**: 361–370.
- Heiossny, Y. and Maftoun, M. (2008) Effects of nitrogen levels, nitrogen sources and zinc rates on the growth and mineral composition of lowland rice. *Journal of Agricultural Science and Technology*. **10**(4): 307-316.
- Hess, M., Barralis, G., Bleiholdera, H., Buhr, L., Eggers, TH., Hack, H. and Stauss, R. (1997) Use of the extended BBCH scale - general for the descriptions of the growth stages of mono- and dicotyledonous weed species. *Weed Research*. **37**, 433-441.
- Hill, J. M. Duxbury, R. K. Gupta, and R. J. Buresh, Eds.), pp. 97–113. ASA, CSSA, SSSA, Madison, WI, ASA Special Publication 65.
- Hobbs, P. R., and Gupta, R. K. (2003) Resource-conserving technologies for wheat in the rice–wheat system. In “Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts” (J. K. Ladha, J. E. Hill, J. M.
- Hussain, S., Maqsood, MA., Rengel, Z., Aziz, T., (2012) Biofortification and estimated human bioavailability of zinc in wheat grains as influenced by methods of zinc application. *Plant and Soil*. **361**:279–290
- Impa, SM., Morete, MJ., Ismail, AM., Schulin, R. and Johnson-Beebout, ES. (2013) Zinc uptake, translocation and grain Zn loading in rice (*Oryza sativa* L.) genotypes selected for Zn deficiency tolerance and high grain Zn. *Journal of Experimental Botany*. **64**(10): 2739-2751.
- Jackson, ML. (1973) Soil chemical analysis, Perntice Hall of India Pvt. Ltd., New Delhi, pp183, 1973.
- Jadhav, AS., Solunke, SS., Alse, UN. and Dhoble, MV. (2006) Growth and yield contributing characters of upland basmati rice as influenced by irrigation and nitrogen. *Annals of Plant Physiology*. **20**(1): 51-55.
- Jana, PK., Ghatak, R., Sounda, G., Ghosh, RK. and Bandyopadhyay, P. (2009) Effect of zinc fertilization on yield N,P,K and Zn uptake by transplanted rice at farmer's field of red and lateritic soils of West Bengal. *Indian Agriculturist*. **53**(3): 129-132.
- Jat, SL., Shivay, YS. and Parihar, CM. (2011) Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa*). *Indian Journal of Agronomy*. **56** (4): 328- 333.
- Jisan, MT., Paul, SK., and Salim, M., (2014) Yield performance of some transplant aman rice varieties as influenced by different levels of nitrogen. *Journal of Bangladesh Agriculture University* **12**(2): 321–324.

- Joshi, E., Kumar, D., Lal, B., Nepalia, V., Gautam, P. and Vyas, A. K. (2013) Management of direct seeded rice for enhanced resource - use efficiency. *Plant Knowledge Journal*. **2**(3): 119-134.
- Keram, KS., Sharma, BL. and Sawarkar, SD. (2012) Impact of zinc application on yield, quality, nutrients uptake and soil fertility in a medium deep black soil (vertisol). *International Journal of Science, Environment and Technology*. **1**(5): 563-571.
- Khattak, SG., Dominy, PJ., Ahmad, W. (2015) Effect of Zn as soil addition and foliar application on yield and protein content of wheat in alkaline soil. *Journal of National Science Foundation Sri Lanka*. **43** (4): 303 – 312
- Kumar, N. and Dawson, J. (2013) Effect of different levels of nitrogen, potash and gibberellic acid (GA3) application on growth and yield attributes of rice (*Oryza sativa* L.). *Progressive Research*. **8**(1): 197-198.
- Kumar, S., Shivay, YS., Kumar, D., Prasad, R. and Kumar, DC. (2008) Effect of levels and source of nitrogen on N P K concentrations, uptake and nitrogen use indices by a high yielding variety and a hybrid of rice. *Indian Journal of Fertilizers*. **2**(11): 53-56.
- Kumar, T. and Kumar, V. (2010) Effect of rates and methods of zinc application on yield, economics and uptake of Zn by rice crop in flood prone situation. *Asian Journal of soil Science*. **4**(1): 96-98.
- Ladha, JK. Kumar, V. Alam, MM. Sharma, S. Gathala, M. Chandna, P. Saharawat, YS. Balasubramanian, V. (2009) Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability of the rice-wheat system in South Asia. In: Ladha JK, Singh Y, Erenstein O, Hardy B (eds) Integrated Crop and Resource Management in the Rice–Wheat System of South Asia. *International Rice Research Institute*, Los Baños, Philippines 69-108.
- Lawal, MI. and Lawal, AB. (2012) Influence of nitrogen rate and placement method on growth and yield of rice (*Oryza sativa* L.) at Kadawa, Nigeria. *Crop Research*. **23**(3): 403-411.
- Lin, HH., Zhang, WY., Xiao, Y., Ying, F., and Yong, WC. (2007) Effects of different nitrogen fertilizer levels on Fe, Mn, Cu and Zn concentrations in shoot and grain quality in rice (*Oryza sativa*). *Rice Science*. **14**(4): 289-294.
- Lindsay, WL. and Norvell, A. (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*. **42**:421-428.
- Lopez-Sanchez, JM., Cloude, SR., and BallesterBerman, JD. (2012) Rice phenology monitoring by means of SAR polarimetry at X-Band. *Geoscience and Remote Sensing*. **50** (7): 2695–2709.

- Mahmudi, J., Sharafi, S., Tanha, M., and Hassanzade, R. (2015) Effect of Zn and K elements on yield and yield components of rice (*Oryza sativa* L.) cv. Tarom Hashemi. *International Journal of Farming and Allied Sciences*, 4-1/1-5/ 31.
- Maiti, PK., Bhattacharya, B. (2013) Effect of nitrogen and potassium on growth and yield of hybrid rice (*Oryza sativa* L.) grown in dry (boro) season. *Journal of Interacademici*. **17**(4): 670-683.
- Maiti, PK. and Bhattacharya, B. (2012) Effect of nitrogen and phosphorus on growth and yield of hybrid rice (*Oryza sativa* L.) grown in dry (boro) season. *Journal of Interacademica*. **16**(3):643-656.
- Mandal, L., Maiti, D. and Bandyopadhyay, P. (2009) Response of zinc in transplanted rice under integrated nutrient management in new alluvial zone of west bengal. *Oryza*. **46**(2): 23-31.
- Manivannan, K., Natarajan, S., Ganapathy, M. and Arivazhagan, K. (2005) Effect of different levels of nitrogen and potassium on growth, nutrient uptake and yield of rice hybrids. *Journal of Ecobiology*. **17**(6): 593-595.
- Mannan, MA., Bhuiya, MSU. and Hossain., SMA. (2008) Effect of nitrogen on the growth and yield of traditional aromatic fine rice varieties in aman season. *Annals of Bangladesh Agriculture*. **12**(2): 9-17.
- Manzoor, Z.; Ali, L.; Akhtar, S.; Ijaz, M.; Akhter, M.; Bhati, M. K.; Rizwan, M.; Hussain, W. (2015) Effect of different nitrogen levels on yield and yield components of fine grain advance rice line pk 8677-18-7-1-14. *Pakistan Journal of Science*. Vol. **67**(3) 235-238
- Martinelli, T., Andrzejewska, J., Salis, M., and Sulas, L. (2014) Phenological growth stages of *Silybum marianum* according to the extended BBCH scale. *Annals of Applied Biology*. ISSN 0003-4746.
- Masum, SM., Ali, MH., Mandal, MSH., Chowdhury, F. and Parveen, K., (2013) The effect of nitrogen and zinc application on yield and some agronomic characters of rice cv. BRRI dhan33, *International Research Journal of Applied and Basic Sciences*, **4** (8): 2256-2263.
- Meier, U., Bleiholder, H., Buhr, L., Feller, C., Hack, H., Heß, M., Lancashire, PD., Schnock, U., Stauß, R., Boom, TVD., Weber, E., Zwerger, P. (2009) The BBCH system to coding the phenological growth stages of plants – history and publications. *Journal for Kulturpflanzen*. **61** (2):41–52.
- Mohapatra, T., Nayak, AK., Raja, R. and Shahid, M. (2013) Vision 2050, Central Rice Research Institute, Cuttack (Odisha).
- Muamba, JK. and Ambara, GS. (2013) Effect of different levels of zinc on growth and uptake ability in rice zinc contrast lines (*Oryza sativa* L.). *Asian Journal of Plant Science and Research*. **3**(3): 112-116.

- Mustafa, GE., Akbar, N., Qaisrani, SA., Iqbal, A., Khan, HZ., Jabran, K., Chattha, AA., Trethowan, R., Chattha, T. and Atta, BM., (2011) Effect of zinc application on growth and yield of rice (*Oryza sativa* L.). *International Journal for Agro Veterinary and Medical Sciences*. **5** (6): 530-535.
- Muthukumararaja, TM. and Sriramachandrasekharan, MV. (2012) Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. *Journal of Agriculture and Technology*. **8**(3): 551-561.
- Naik, SK. and Das, DK. (2008) Relative performance of chelated zinc and zinc sulphate for lowland rice (*Oryza sativa* L.). *Nutrient Cycling in Agroecosystems*. **81**(3): 219-227.
- Naik, SK. and Das, DK. (2010) Evaluation of various zinc extract ants in lowland rice soil under the influence of zinc sulfate and chelated zinc. *Communications in Soil Science and Plant Analysis*. **41**(4): 122–134.
- Narwal, RP., Malik, RS. and Dahiya, RR. (2011) Enrichment of wheat varieties with respect to zinc application. *3rd International Zinc Symposium, Hyderabad, India*. pp 10-14.
- Nori, H., Halim, RA. and Ramlan, MF. (2008) Effects of nitrogen fertilization management practice on the yield and straw nutritional quality of commercial rice varieties. *Malaysian Journal of Mathematical Sciences*. **2**(2): 61-71.
- Nwaz, M., Iqbal, N., Saleem, MU., Ashraf, MM. (2015) Effect of ZnSO₄ mixed with different fertilizers on paddy yield of fine grain rice. *Applied Sciences and Business Economics*. **2**(1): 8-12
- Pandey, S. and Velasco, LE. (1999) Economics of alternative rice establishment methods in Asia: a strategic analysis. In: Social Sciences Division Discussion Paper, *International Rice Research Institute*, Los Banos, Philippines.
- Pandey, S., Velasco, L. (2005) Trends in crop establishment methods in Asia and research issues. In “Rice Is Life: Scientific Perspectives for the 21st Century” Toriyama K, Heong KL, Hardy B (eds.) International Rice Research Institute, Los Banos, Philippines and Japan *International Research Center for Agricultural Sciences*, Tsukuba, Japan pp 178–181.
- Paul, SK., Islam, MS., Sarkar, MAR., Das, KR. And Islam, SMM. (2016) Impact of variety and levels of nitrogen on the growth performance of HYV transplant Aman rice. *Progressive Agriculture*, **27**: 32-38.
- Phattarakul, N., Rerkasem, B., Li, LJ., Wu, LH., Zou, CQ., Ram, H., Sohu, VS., Kang, BS., Surek, H., Kalayc, M., Yazici, A., Zhang, FS. and Cakmak, I. (2012). Bio fortification of rice grain with zinc through zinc fertilization in different countries. *Plant and Soil*. **361**: 131–141.
- Piper, CS. (1966) Soil and plant analysis, *Hans Publications, Bombay, India*.

- Pooniya, V. and Shivay, YS. (2012) Summer green manuring crops and zinc fertilization on productivity and economics of basmati rice (*Oryza sativa* L.). *Archives of Agronomy and Soil Science*. **58**(6): 593–616.
- Pooniya, V. and Shivay, YS. (2013) Enrichment of basmati rice grain and straw with zinc and nitrogen through ferti-fortification and summer green manuring under indo-gangetic plains of India. *Journal of Plant Nutrition*. **63**(1): 91-117.
- Pooniya, V., Shivay, YS., and Rana, A. (2012) Enhancing soil nutrient dynamics and productivity of basmati rice through residue incorporation and zinc fertilization. *European Journal of Agronomy*. **41**(2): 28-37.
- Puteh, AB. and Mondal, MA. (2014). Growth and yield performance of rice as affected by nitrogen rate. *Life Science Journal*. **11**(8):653-655.
- Qiao, JF., Liu, ZH., Deng, SY., Ning, HF., Yang, XY., Lin, ZM., Li, GH., Wang, QS., Wang, SH., Ding, Y. (2011) Occurrence of perfect and imperfect grains of japonica rice as affected by nitrogen fertilizer. *Plant and Soil*. **349**: 191-202.
- Quijano-Guerta, C. Kirk, GJD. Portugal, AM. Bartolome, VI. and Mc Laren, GC. (2002) Tolerance of rice germplasm to zinc deficiency. *Field Crops Research*. **76**: 123-130.
- Rahman, A., Yasin, M., Akram, M. and Awan, ZA. (2012) Response of rice to zinc-application and different N-sources in calcareous soil. *Asian Journal of Plant Science and Research*. **3**(3): 102-106.
- Rahman. MH., Ali. MH., Ali. MM and Khatun. MM (2007) Effect of different level of nitrogen on growth and yield of transplant aman rice cv. BRRI dhan 32. *International Journal of Sustainable Crop Production*. **2**(1): 28-34.
- Rana, WK., and Kashif, SR. (2014) Effect of different Zinc sources and methods of application on rice yield and nutrients concentration in rice grain and straw. *Journal of Environmental and Agricultural Sciences*. **1**(2): 2313-8629.
- Rashid, A. (1996) Secondary and micronutrient. In: A. Rashid and K. S. Memon, (eds). Soil Science. *National Book Foundation, Islamabad*.
- Reza, Y., Salman, D. and Esmaeil, Y. (2012) Role of zinc fertilizer on grain yield and some qualities parameters in Iranian rice genotypes. *Annals of Biological Research*. **3**(9): 4519-4527.
- Ruel, M. T. and Bouis, H. E. (1998) Plant breeding: a long-term strategy for the control of zinc deficiency in vulnerable populations. *American Journal of Clinical Nutrition*. **68**:488S- 494.
- Saeed, AQ. and saeed, AQ. (2011) Effect of method and time of zinc application on growth and yield of rice (*Oryza sativa* L.). *Original Research*. **5**(6): 530-535.
- Sanchez, P. A. (1973). Puddling of tropical soils & effects on water losses. *Society of Soil Science*. **115**: 303–308.

- Sandstead HH. (1991) Zinc deficiency: a public health problem? *American Journal of Diseases of Children*. 145:853-9.
- Sharma, P. K., Ladha, J. K., and Bhushan, L. (2003). Soil physical effects of puddling in rice-wheat cropping systems. In “Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts” (J. K. Ladha, J. E. Shehzad, MA., Fiaz, BM., Tasneem, G., and Yasin, MI. (2012) Boron, zinc and microtone effects on growth, chlorophyll contents and yield attributes in rice (*Oryza sativa* L.) cultivar. *African Journal of Biotechnology*. **11**(48): 10851-10858.
- Shivay, YS. and Prasad, R. (2012) Zinc-coated urea improves productivity and quality of basmati rice (*oryza sativa* L.) under zinc stress condition. *Journal of Plant Nutrition*. **35**(6): 928-951.
- Shivay, YS., Kumar, D. and Prasad, R. (2008) Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice–wheat cropping system. *Nutrient Cycling in Agroecosystems*. **81**(3):229-243.
- Singh, M. and Singh, SP. (1981) Effect of nitrogen and zinc on the yield of submerged rice and uptake of N and Zn on unlimed and limed soils. *Plant and Soil*. **62** (2): 183-192.
- Singh, M. and Singh, SP. (2012) Effect of nitrogen and zinc on the yield of submerged rice and uptake of nitrogen and zinc on unlimed and limed soils. *Journal of Agricultural Science and Technology*. **42**(2): 372-379.
- Singh. K. and Tripathi, HP. (2007) Growth, yield, N uptake and quality of direct seeded rice (*Oryza sativa* L.) as influenced by nitrogen and weed control measures. *Journal of Farming Systems Research & Development*. **13**(2): 214-219.
- Sridevi, G., Rajkannan, B. and Surendran, U. (2010) Effect of zinc enriched FYM and cow dung on yield of rice (ADT-45). *Crop Research*. **40**(1,2 &3): 25-28.
- Subbiah, BV. and Asija, GL. (1956) A rapid procedure for estimation of available nitrogen in soils. *Current Sciences*. **28** (8): 259-260.
- Thieu ThiPhong Thu Yamakawa, T. and Moe, K. (2014) Effect of nitrogen application timing on growth, grain yield and eating quality of the KD 18 and TH3-3 rice varieties. *Journal of the Faculty of Agriculture, Kyushu University*. **59**(1): 55-64.
- Tripathi, R. P., Sharma, P., and Singh, S. (2005) Tillage index: An approach to optimize tillage in rice-wheat system. *Soil and Tillage Research*. **80**, 125–137.
- Varshney, P., Singh, SK. and Srivastava, PC. (2008) Frequency and rates of zinc application under hybrid rice - wheat sequence in a mollisol of Uttarakhand. *Journal of the Indian Society of soil Science*. **56**(1): 92-96.

- Viraktamath, BC., Bentur, JS., Rao, KV. and Sain, M. (2011) Rice Scenario. Vision 2030, Directorate of Rice Research Rajendranagar, Hyderabad. pp1.
- Walkley, A. and Black, CA. (1934). Estimation of soil organic carbon by the chromic acid titration method, *Soil Science*. 37: 29-38.
- Wei, Y., Shohag, MJI. and Yang, X.(2012) Biofortification and bioavailability of rice grain zinc as affected by different forms of foliar zinc fertilization. *Plant and Soil*. 7(9): 35-42.
- Welch, R. M. and Graham, R. D. A new paradigm for world agriculture: meeting human needs: productive, sustainable, nutritious. *Field Crop Research*. 60:1-10, 1999.
- Xue, YF., Yue, SC., Zhang, YQ., Cui, ZL., Chen, XP., Yang, FC., Cakmak, I., McGrath, SP., Zhang, FS., Zou, CQ. (2012). Grain and shoot zinc accumulation in winter wheat affected by nitrogen management. *Plant and Soil*. 361:153–163.
- Yadav, GS., Kumar, D., Shivay, YS. and Singh, H. (2010). Zinc-enriched urea improves grain yield and quality of aromatic rice. *Better Crops*. 94 (2).
- Yin, HJ., Gao, XP., Stomph, T., Li, LJ., Zhang, FS. And Zou, CQ. (2016). Zinc Concentration in Rice (*Oryza sativa* L.) Grains and Allocation in Plants as Affected by Different Zinc Fertilization Strategies. *Communications in Soil Science and Plant Analysis*, 47:6, 761-768
- Youseftabar, S., Fallah. A. and Daneshiyan, J. (2012). Effect of split application of nitrogen fertilizer on growth and yield of hybrid rice (GRH1). *Australian Journal of Basic and Applied Sciences*. 6(6): 1-5.
- Zhang, Y., Sun, Y., YouLiang, YM., Karim, R., Xue, Y., Yan, P., Menga, Q., Cui, Z., Cakmak, I., Zhang, F. and Zou. (2012). Zinc biofortification of wheat through fertilizer applications in different locations of China. *Field Crops Research*. 5(125): 1-7.
- Zou, CQ., Zhang, YQ., Rashid, A., Ram, H., Savasli, E., Arisoy, RZ., Ortiz, MI., Simunji, S., Wang, ZH., Sohu, V., Hassan, M., Kaya, Y., Onder, O., Lungu, O., Yaqub, MM., Joshi, AK., Zelenskiy, Y., Zhang, FS. and Cakmak. I. (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil*. 361:119–130.

